

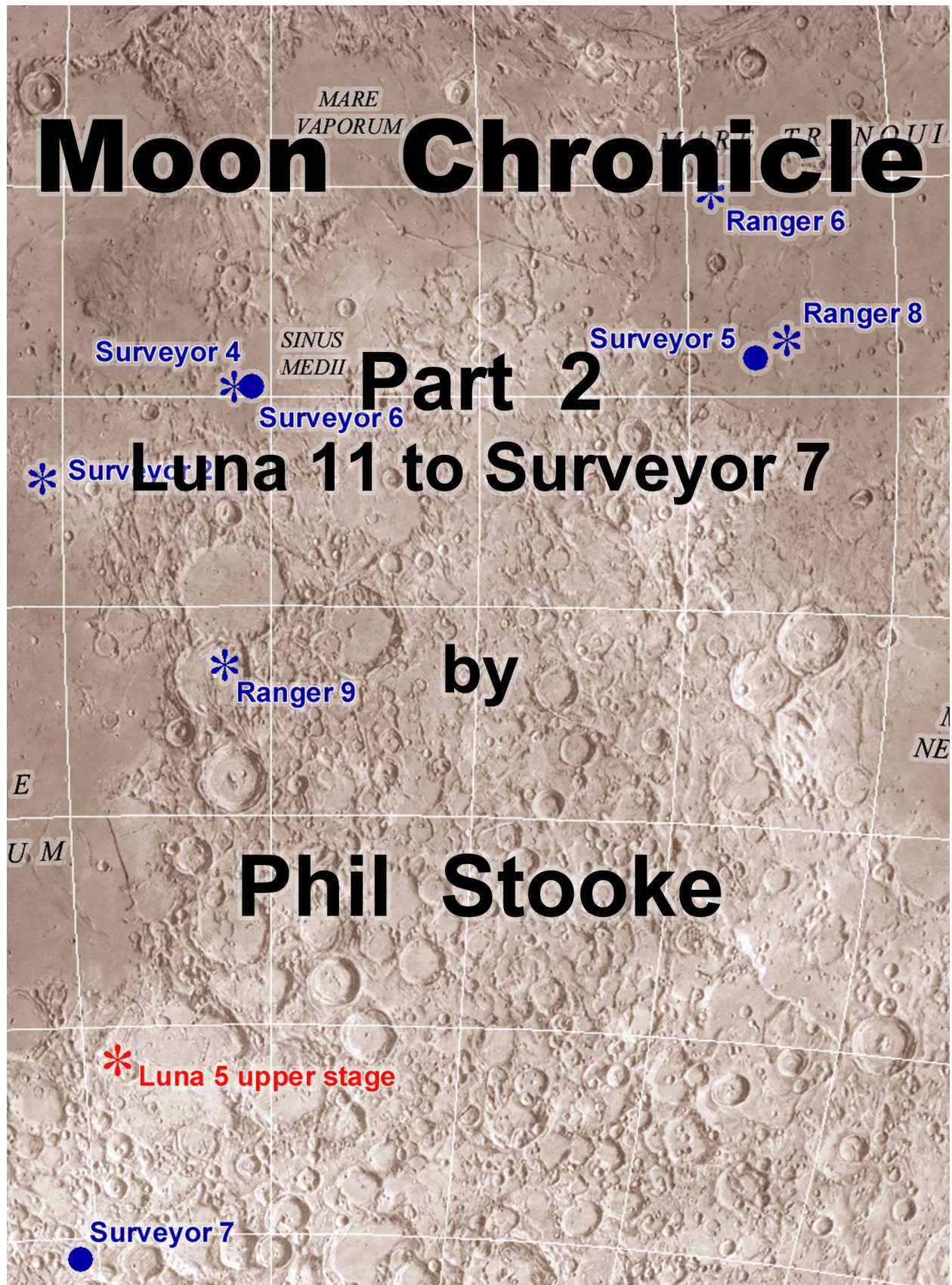
Moon Chronicle

Part 2

Luna 11 to Surveyor 7

by

Phil Stooke



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Introduction

This second part of the Moon Chronicle covers most of the Surveyor missions to the Moon (Surveyor 1 was described in Part 1), most of the Lunar Orbiter missions, and preparations for Apollo. The Soviet Union was also flying missions to the Moon, most notably for this volume Luna 13, but its greatest achievements were still to come.

Surveyor images were archived as photographic negatives, as was customary at the time (a digital file would be almost useless to most people), and because Apollo progressed so quickly and overshadowed everything else they were perhaps not given all the treatment they might have had. In 2014 a project to scan the negatives and make them available digitally was initiated (<https://sic.lpl.arizona.edu/surveyor-digitization>). Its funding ceased before it could be concluded, but work continued slowly, particularly on creating the necessary metadata for each image. At the time of writing (January 2025) the project was still not completed but was nearing the end. The new data will allow the creation of surface panoramas vastly superior to those shown here.

Figure and Table numbers continue from volume to volume in the Chronicle. A map of all landings and impacts on the Moon covered in this volume of the Chronicle, and a table with details of them, are included as a small appendix (Figure A1, Table A1) at the end of this volume.

Spacecraft image credits:

Lunar Reconnaissance Orbiter camera (LROC) data: NASA/GSFC/Arizona State University, and Robinson, M.S., *et al.* (2010). Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview, *Space Science Reviews*, v. 150, pp. 81-124. <https://doi.org/10.1007/s11214-010-9634-2>

Lunar Reconnaissance Orbiter Laser Altimeter (LOLA): Smith, D.E., Zuber, M.T., Jackson, G.B. *et al.*, 2010. The Lunar Orbiter Laser Altimeter investigation on the Lunar Reconnaissance Orbiter mission. *Space Science Reviews*, v. 150, pp.209-241. <https://doi.org/10.1007/s11214-009-9512-y>

Lunar QuickMap (<https://quickmap.lroc.im-ldi.com>), developed by NASA, Arizona State University and Applied Coherent Technology Corp.

Luna: All Luna images, maps derived from them and any other material originating from the Soviet Union were provided courtesy of V. V. Shevchenko, Sternberg State Astronomical Institute, Moscow and his colleagues. These materials were not copyrighted.

Lunar Orbiter: NASA/JSC, Lunar and Planetary Institute (<https://www.lpi.usra.edu/resources/lunarorbiter/#support>), Lunar Orbiter Image Recovery Project: (<https://catalog.archives.gov/id/77811149>)

Surveyor: Surveyor images used in the Chronicle were scanned by the author at the Lunar and Planetary Institute, the Lunar and Planetary Laboratory of the University of Arizona and at the U.S. Geological Survey in Flagstaff, Arizona.

First release: October 2025.

Edit: November 2025 (Figure 71; Surveyor 5 retrorocket)

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24 August 1966: Luna 11

The Soviet Union's 3616 kg automatic station Luna 11 was similar to Luna 10 in its appearance and mission. It was launched at 08:09 UT from Baikonur and entered a parking orbit before departing for the Moon. After a trajectory correction at 19:02 UT on 26 August it entered a 164 km by 1194 km, 178 minute period lunar orbit inclined 27° to the equator at 21:49 UT on 27 August (28 August by Moscow time). Luna 10's orbital module detached from its carrier spacecraft in orbit, but Luna 11's may not have done.

Scientific investigations included measuring lunar gamma-ray and X-ray emissions to estimate the Moon's surface composition, studying the lunar gravitational field, micrometeorites, and particle radiation near the Moon. The particle radiation measurements detected solar wind enhancements caused by flares several times during the mission (Grigorev *et al.*, 1968). A camera would have returned pictures of the surface, but attitude control problems prevented successful imaging operations. Luna 11 conducted the first lunar bistatic radar experiment, reflecting its signal off the lunar surface to be received on Earth. The reflected signal revealed surface characteristics, particularly the density of the regolith down to a depth of several metres (Yakovlev and Efimov, 1967; Yakovlev *et al.*, 1968). Luna 11 also tested in vacuum conditions the wheels to be used on future rovers. 277 orbits and 137 radio transmissions were completed before the batteries failed at about 02:03 UT on 1 October 1966.

Grigorev, N. L., Lutsenko, V. N., Maduyev, V. L. *et al.*, 1968. Registration of solar cosmic rays on the AMS "Luna-11". NASA translation ST-PF-SCR-10684.

Yakovlev, O.I., Efimov, A.I. and Matyugov, S.S., 1968. Scattering of Meter Radio Waves by the Lunar Surface. *Cosmic Research*, v. 6, pp. 366-370.

Yakovlev, O.I. and Efimov, A.I., 1967. Studies of Reflection of Meter-Length Radio Waves by the Lunar Surface. *Doklady Akademii Nauk SSSR*, v. 174, pp. 583-584.



1966: Lunar Orbiter 1 Site Screening

Lunar Orbiter 1 images were screened at MSC in Houston and at NASA's Langley Research Center in Hampton, Virginia for suitable Apollo landing sites as soon as good prints became available. The first step was to identify areas on the new images which were relatively smooth, large enough to contain the 7.9 by 5.3 km landing ellipse, and had a clear approach from the east (no large hills or craters to complicate use of the landing radar). When suitable ellipses had been located a more detailed analysis could be undertaken, involving thorough analysis of the highest resolution frames. For each ellipse, statistics were gathered for craters, blocks and areas deemed too rough for landing. The ellipses could then be ranked for landing safety.

This procedure was hampered by the poor quality of the high resolution frames from Lunar Orbiter 1, but the medium resolution images were adequate to begin the process. Figure 53 show the results of this site screening for the nine Orbiter 1 prime sites (Lunar Orbiter Photo Data Screening Group, 1966). These images have been reproduced from the original materials, with cosmetic enhancements, but image quality reflects the nature of the originals. Ellipses show the specific sites studied. The black ellipses were preferred. White ellipses are too rough or have poor approaches. The nested outer, middle and inner ellipses denote 99%, 90% and 50% probabilities of landing within the ellipse.

The association between Apollo sites and Surveyor targeting is clear in Figure 53, where the Surveyor 3 target was the A-7-1 ellipse and the original Surveyor target in Sinus Medii was the A-5-4 ellipse. Surveyor 1 landed on the edge of ellipse A-9.2b-4, but a mountain east of the ellipse made the approach unacceptable for Apollo.

Lunar Orbiter Photo Data Screening Group, 1966. *Preliminary terrain evaluation and Apollo landing site analysis based on Lunar Orbiter 1 photography*. Langley Working Paper LWP-323, November 1966.

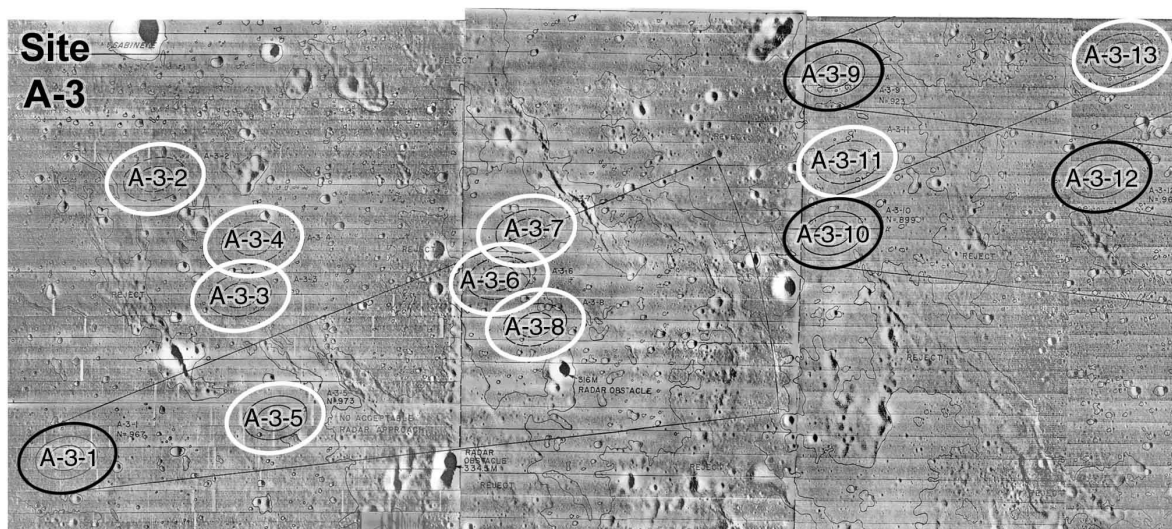
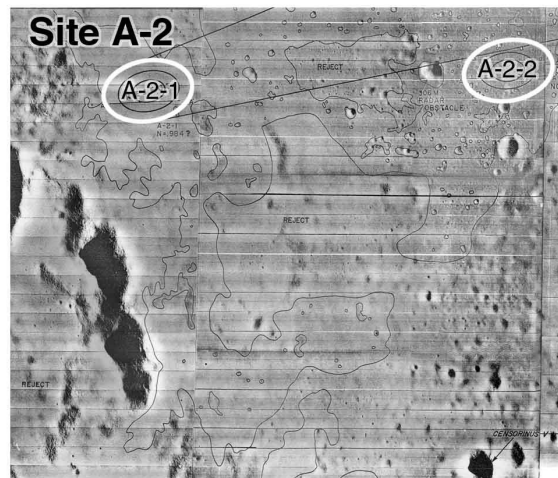
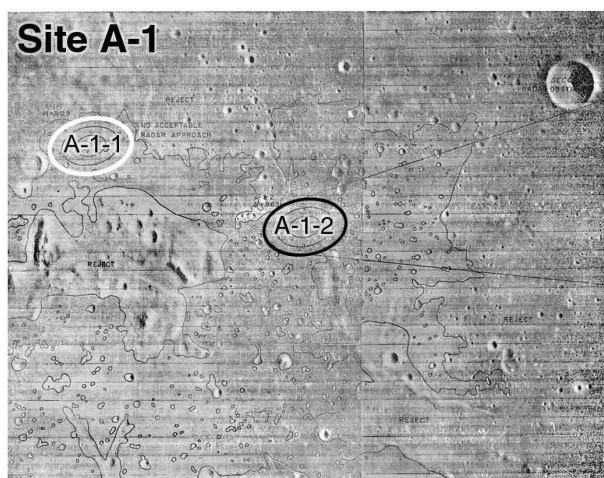
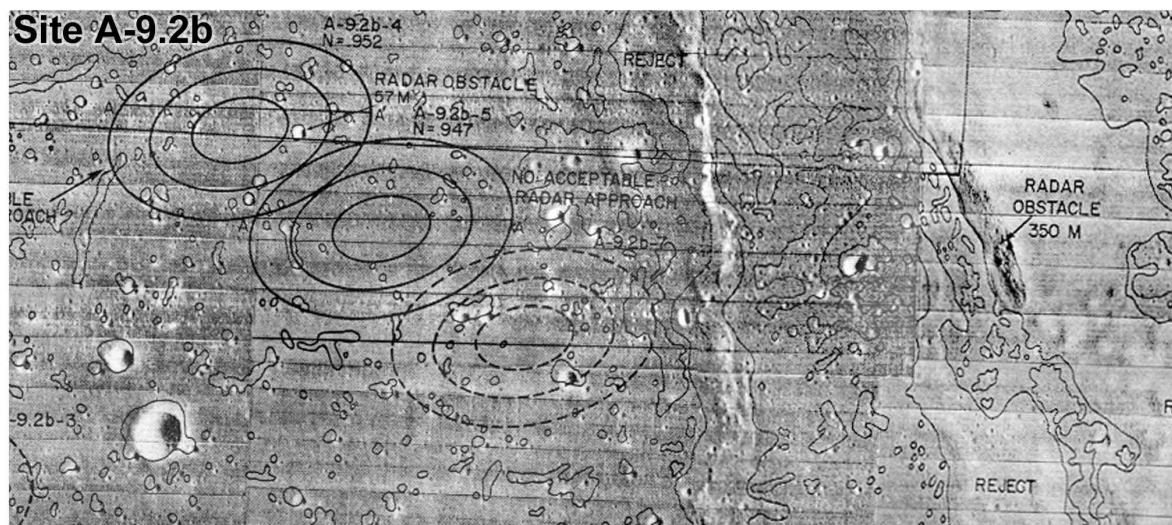
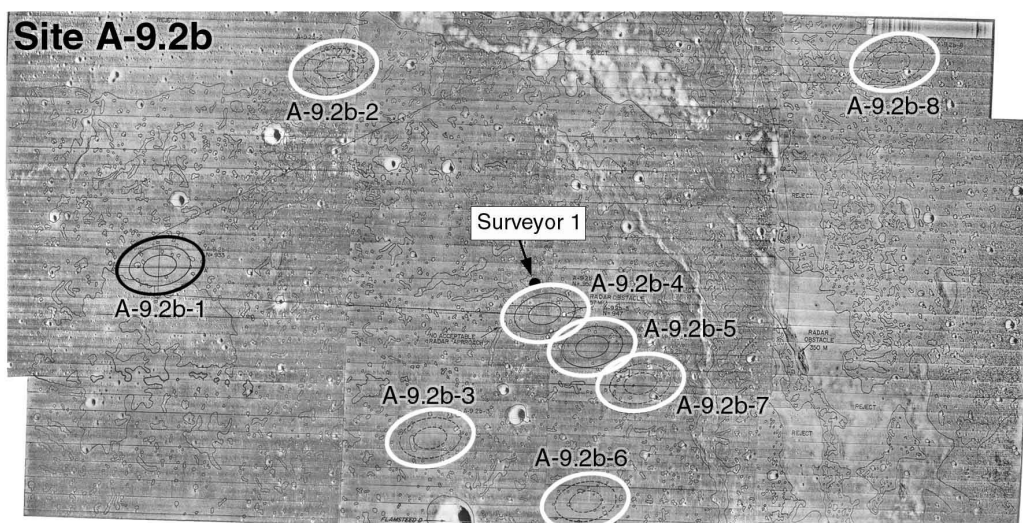
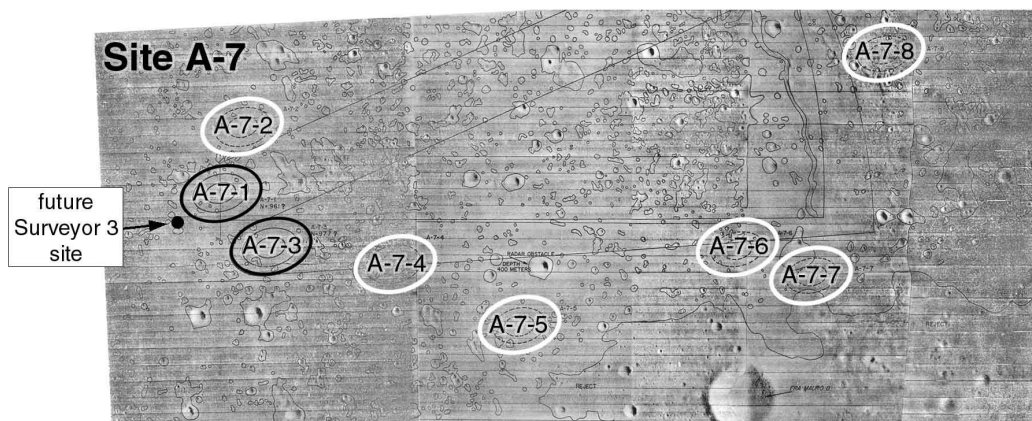
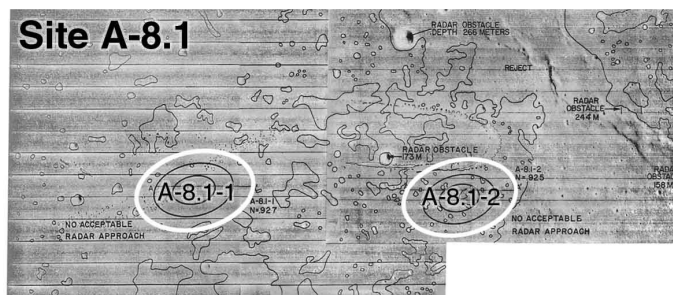
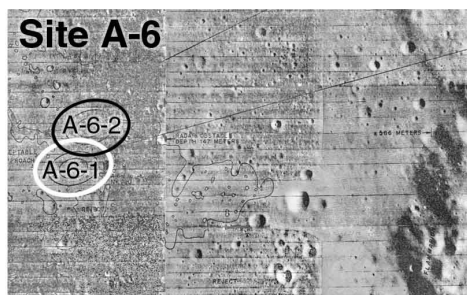
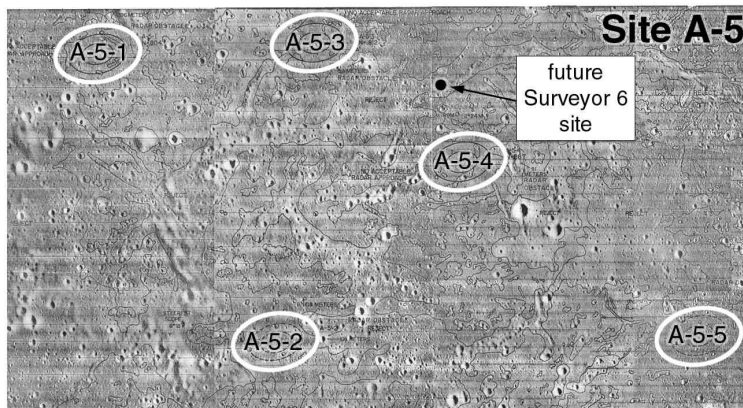
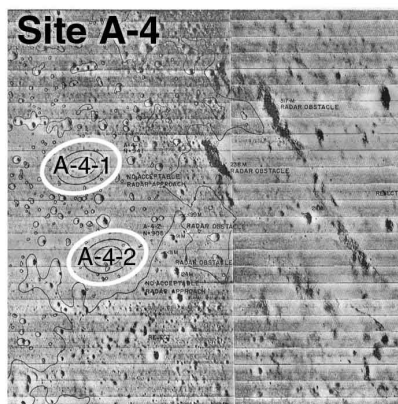


Figure 53 (both pages): Lunar Orbiter 1 site screening results. The background images are the original mosaics of Lunar Orbiter 1 frames, including defects. The first panel shows an example of a screening map of Site A-9.2b at larger scale. Scale is indicated by the ellipse size (7.9 by 5.3 km).





20 September 1966: Surveyor 2

This second NASA soft landing attempt ended in failure. The 292 kg Surveyor 2 was launched on an Atlas-Centaur booster from Cape Kennedy at 12:32 UT. Surveyor 2 was to return images of its landing site, engineering data on landing dynamics, and radar reflectivity and thermal data on the lunar surface. Following injection from a parking orbit into its lunar trajectory, the spacecraft operated perfectly up to its trajectory correction at 05:00 UT on 21 September. Then one of the three vernier engines (used for the trajectory correction as well as the final landing) failed to ignite, causing the spacecraft to tumble. Attempts were made to restore control without success, and 28.5 h after the vernier failure, with batteries almost depleted, the main retrorocket and remaining verniers were fired. Contact was lost 30 s later. Surveyor 2 crashed at 9:35 UT on 22 September, southeast of Copernicus at about 4° S, 11° W. The position is poorly constrained and the circle in Figure 54B is only a rough estimate of uncertainty.

The pre-launch target was a 50 km radius circle in Sinus Medii around 0.0° N, 0.66° W (Figure 54C). A site at 3° S, 23° W (later used for Surveyor 3) was the backup in case of a launch delay. The launch was so precise that a smaller target ellipse was designated after launch, with its center at 0.55° N, 0.83° W. This avoided obstacles including the hills forming the rim of Oppolzer to the south. If no trajectory correction or braking had occurred impact would have been at 0.052° S, 5.29° W (JPL 1967, Thornton *et al.*, 1968). Figure 54C also shows the uncorrected impact point of Surveyor 4. The Centaur upper stage passed into a heliocentric orbit and was rediscovered 54 years later as a potential asteroid (2020 SO) by Pan-STARRS 1 (Panoramic Survey Telescope and Rapid Response System, a large sky survey system) at Haleakala, Hawaii on 17 September 2020. It approached Earth slowly and was temporarily captured into an unstable Earth orbit, making its closest approach on 1 December 2020. After two circuits of Earth it escaped again into a heliocentric orbit, destined to repeat this process until it eventually collides with the Moon or burns up in Earth's atmosphere.

JPL 1967. *Surveyor II mission report*, JPL Tech. Rep. 32-1086. Pasadena: Jet Propulsion Laboratory.
Thornton, T. H., Labrum, R. G., Wollenhaupt, W. R. *et al.*, 1968. *The Surveyor I and Surveyor II flight paths and their determination from tracking data*. JPL Technical Report 32-1285, 1 August 1968. Pasadena, California: Jet Propulsion Laboratory.



22 October 1966: Luna 12

The 1620 kg Luna 12 was another Soviet lunar orbiter, and the first to transmit images of the lunar surface from orbit. It was launched from Baikonur at 08:42 UT and placed in a parking orbit before departing for the Moon. It consisted of a carrier spacecraft like that of Lunas 9 and 10, and a redesigned instrument module. A trajectory correction was made on 23 October. Luna 12 entered a 103 km by 1742 km, 205 minute period lunar orbit inclined 20° to the lunar equator at 20:47 UT on 25 October. The mass in orbit was 1136 kg.

The spacecraft was equipped with an experimental imaging system (mounted on the carrier spacecraft) that obtained and transmitted pictures of the lunar surface. The pictures were taken on film, processed and scanned for transmission, as on Luna 3 and Zond 3. They contained 1100 scan lines with a maximum resolution of about 5 m/pixel, revealing craters as small as 15 to 20 m in diameter. Pictures of the lunar surface in the vicinity of Aristarchus crater were returned on 27 October, and of Mare Imbrium on 29 October (Figure 55). The number of images taken was small, said to be 28 high resolution and 14 low resolution frames, and photography may have been delayed for two days after entering orbit by an initial attitude control problem. These images would have been adequate to plan human surface exploration, though many more would have been needed, and in areas closer to the equator.

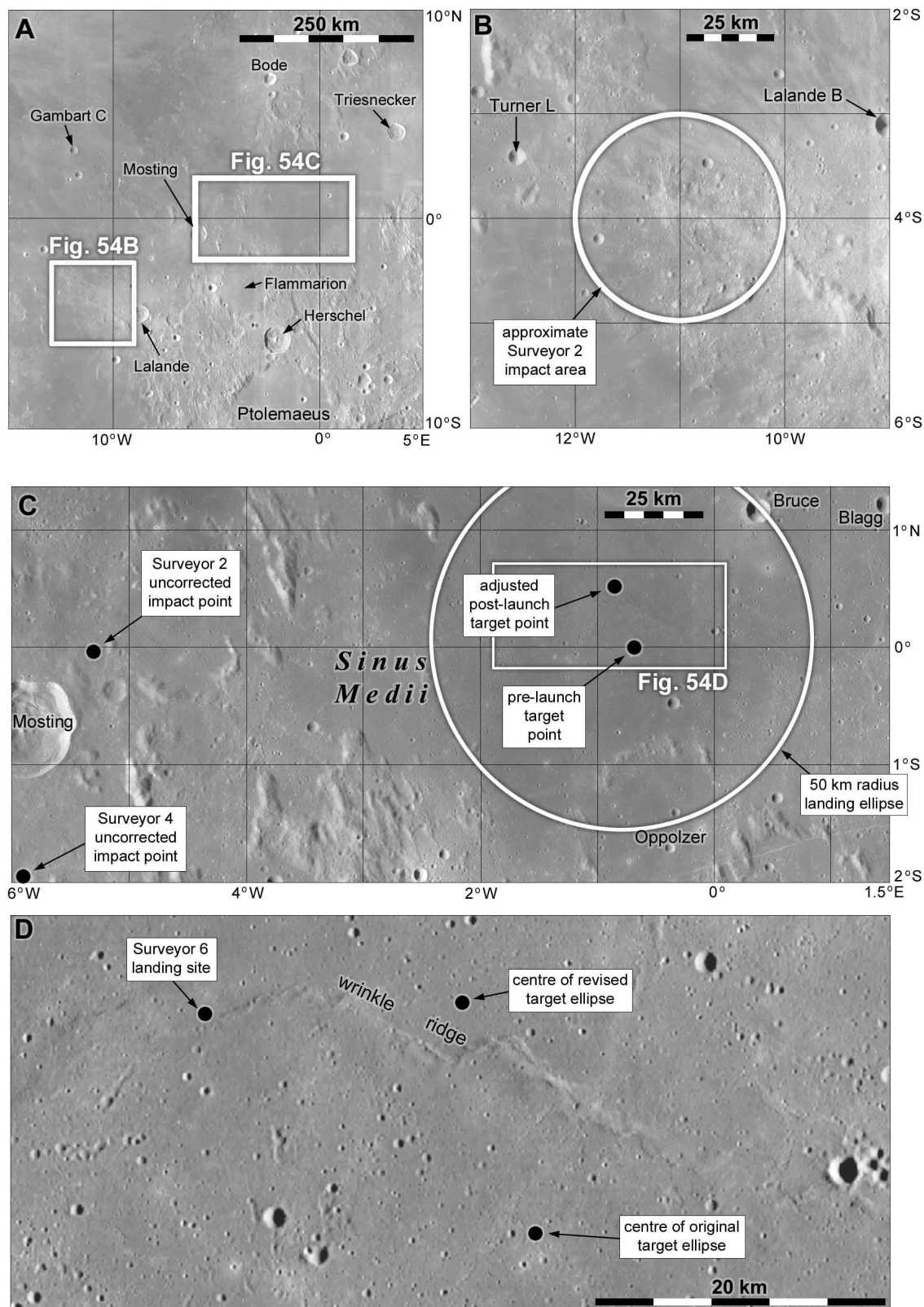


Figure 54: Surveyor 2 target and impact points. A: Context map. B: The Surveyor 2 impact region. C: Target, revised target and uncorrected impact point for Surveyor 2, including the uncorrected impact point for Surveyor 4. D: close view of the centre of the Surveyor 2 target ellipse, also showing the Surveyor 6 landing site.

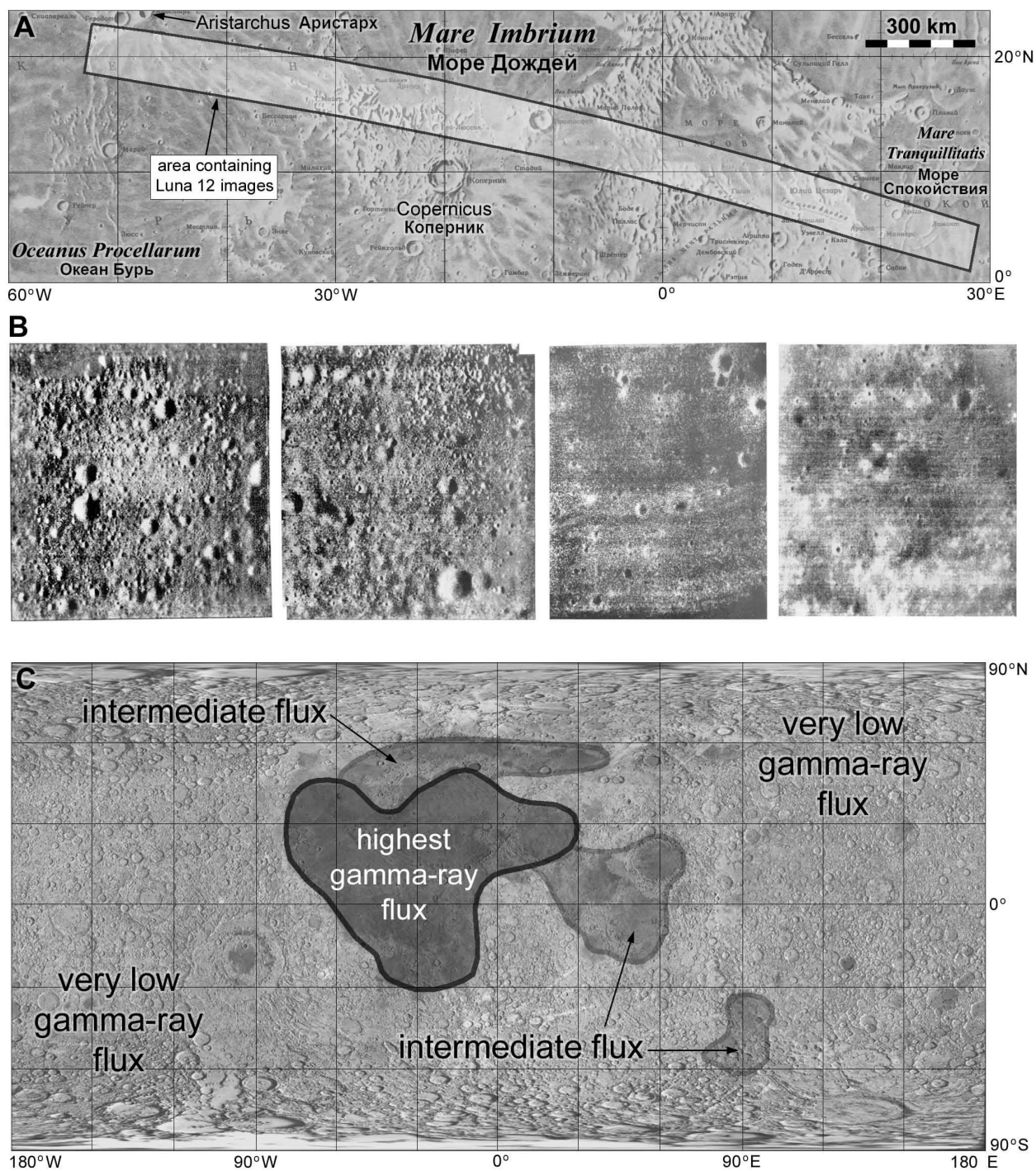


Figure 55: Luna 12 orbital data. A: area including Luna 12 images. B: representative Luna 12 images. C: interpretation of the results of the Luna 10, 11 and 12 lunar gamma ray experiments. The base map for Figure 55A is part of *Polnaya Karta Luni*, original scale 1:5 million, Nauka, Moscow, 1979. Figure 55C is adapted from Figure 2.1.29 of Surkov (1990). Its base map is a USGS shaded relief map in Simple Cylindrical projection.

Luna 12 carried other instruments similar to those of Luna 10, including a gamma ray spectrometer which strengthened the findings of that mission regarding the composition of the lunar surface (Figure 55C). Electric motors for use on later Lunokhod rovers were tested during the mission. The orbit dropped as low as 20 km at periapsis before being raised for a short time, but contact ceased on 19 January 1967 after 602 lunar orbits and 302 transmissions. Luna 12 probably crashed at an unknown location later in 1967. Cheremukhin *et al.* (1968) say that Luna 12 was spinning during collection of X-ray data from October 1966 to January 1967. The Luna 12 images were taken over the area shown in Figure 55A, but the precise locations of the images and the total area covered are not known. Four images are displayed in Figure 55B, each covering an area approximately 5 km across. The two images at left are of areas about 250 km apart within the ray system of the crater Aristarchus. The two images at right (TASS, 1966) are in southern Mare Imbrium. These images were made available by MIIGAiK.

Figure 55C shows the general pattern of variations which emerged at low resolution from the gamma-ray measurements of Lunas 10, 11 and 12 combined Surkov (1990). Higher latitude areas were covered only by Luna 10. The gamma ray fluxes were used to estimate the amounts of radioactive elements in the crust. The results were consistent with a basaltic composition for the maria and an ultrabasic (very low silica) composition for the highlands and far side. Increased radioactivity over the western maria hinted at compositional variations among the mare basalts. No evidence for granite-like materials was seen. The spatial resolution of the observations is not known.

Cheremukhin, G.S., Dmitriev, A.B., Mandelshtam, S.L. *et al.*, 1968. X-radiation of the moon and Roentgen cosmic background according to data of AMS "Luna-12". NASA translation no. ST-LPS-RAD-10689.

<https://ntrs.nasa.gov/api/citations/19680009928/downloads/19680009928.pdf>

Surkov, Yu. A., 1990. *Exploration of terrestrial planets from spacecraft: instrumentation, investigation, interpretation*. Chichester: Ellis Horwood.

TASS, 1966. Luna 12 transmits photographs. TASS communique from Pravda no. 303 (17620), 30 October 1966. NASA translation ST-PR-LPS-10-534.

<https://ntrs.nasa.gov/api/citations/19670002405/downloads/19670002405.pdf>



06 November 1966: Lunar Orbiter 2

Lunar Orbiter II, essentially identical to Orbiter 1, was launched at 23:21 UT from Cape Kennedy Launch Complex 13 on an Atlas-Agena D booster, put in a parking orbit and 14 minutes later placed on its 94 hour flight to the Moon. A trajectory correction was made on 8 November, 265,485 kilometers from Earth. The spacecraft entered lunar orbit at 7:26 UT on 10 November. The initial orbit was 196 by 1850 km with an inclination of 11.8°. Perilune was lowered to 49.7 km at 9:58 UT on 15 November after 33 orbits. The imaging phase of the mission began on 18 November (Boeing Co., 1967a, Hansen, 1970).

Thirteen potential Apollo landing sites and seventeen supplementary sites were targeted. The final image was taken on the afternoon of 25 November. A total of 209 high resolution and 208 medium resolution frames were taken over 40 orbits, with resolutions down to 1 m. Readout began on 26 November. It terminated one day early, 6 December, when a transmitter failed. Three medium-resolution and two high-resolution photos of primary site 1 were lost, though full low-resolution coverage of the site was obtained and other data continued to be transmitted.

Lunar Orbiter 2's photographic coverage is shown in Figures 56-58. Nearside photography from Lunar Orbiter 2 covered the areas shown in Figure 56. Prime sites are shown with black outlines, supplementary sites with gray outlines. Coverage of the Apollo zone was extended, and some of the high resolution coverage lost by Lunar Orbiter 1 was made up. These Orbiter 2 (Mission B) prime sites differ slightly from those considered by the Apollo Site Selection Board on 1 June 1966 (Figure 49). Four images were taken with the camera tilted towards the horizon to show the surface obliquely, including one of Copernicus which became famous as the 'picture of the century' (Figure 56B). Because Lunar Orbiter 2's image motion compensation mechanism worked correctly, this mission provided the first very high resolution images for Apollo site selection.

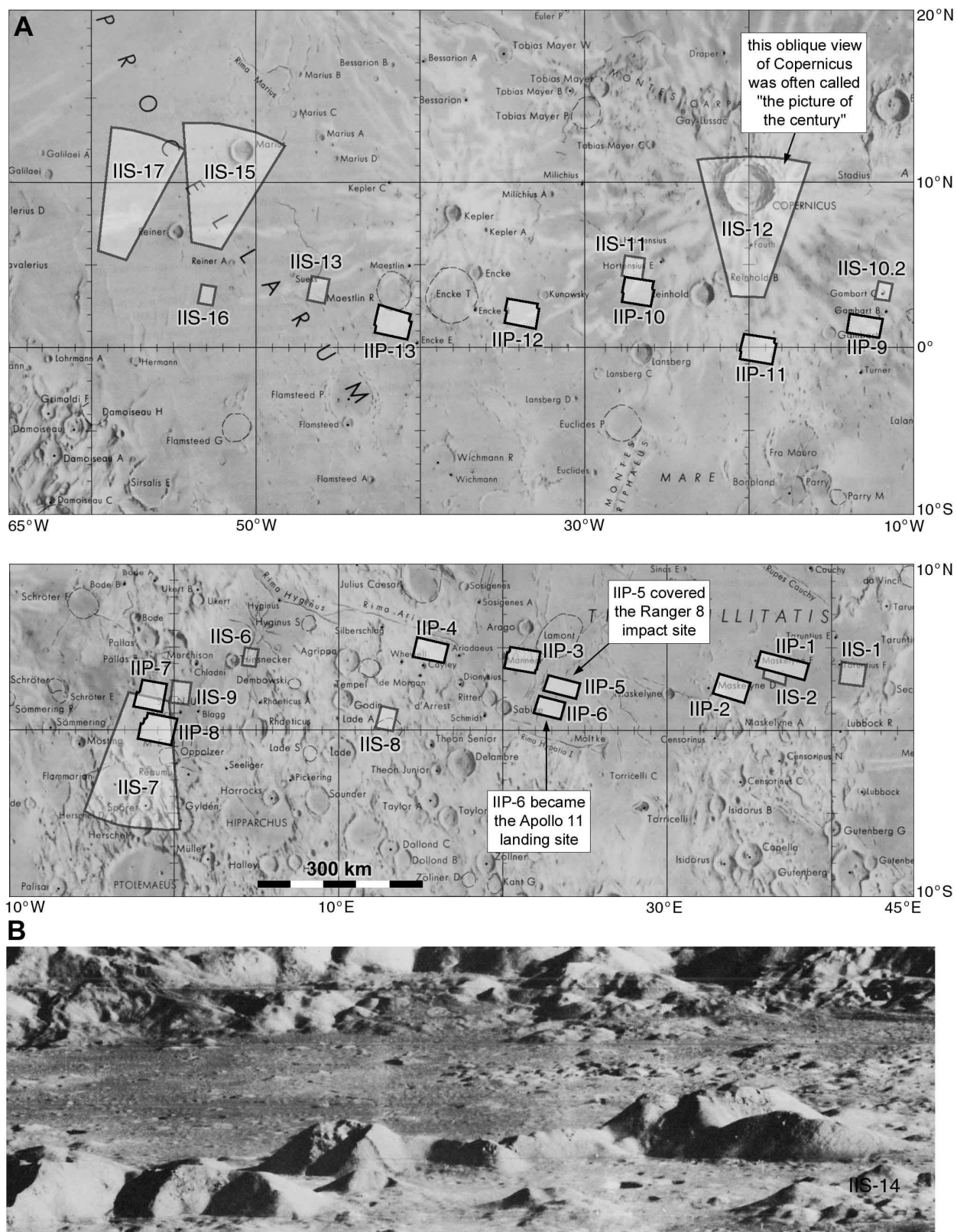


Figure 56: Lunar Orbiter 2 nearside coverage. A: Prime and supplementary sites on the nearside. B: Part of the 'Picture of the Century' (image II-162-H3) showing the central peaks and northern wall of Copernicus.

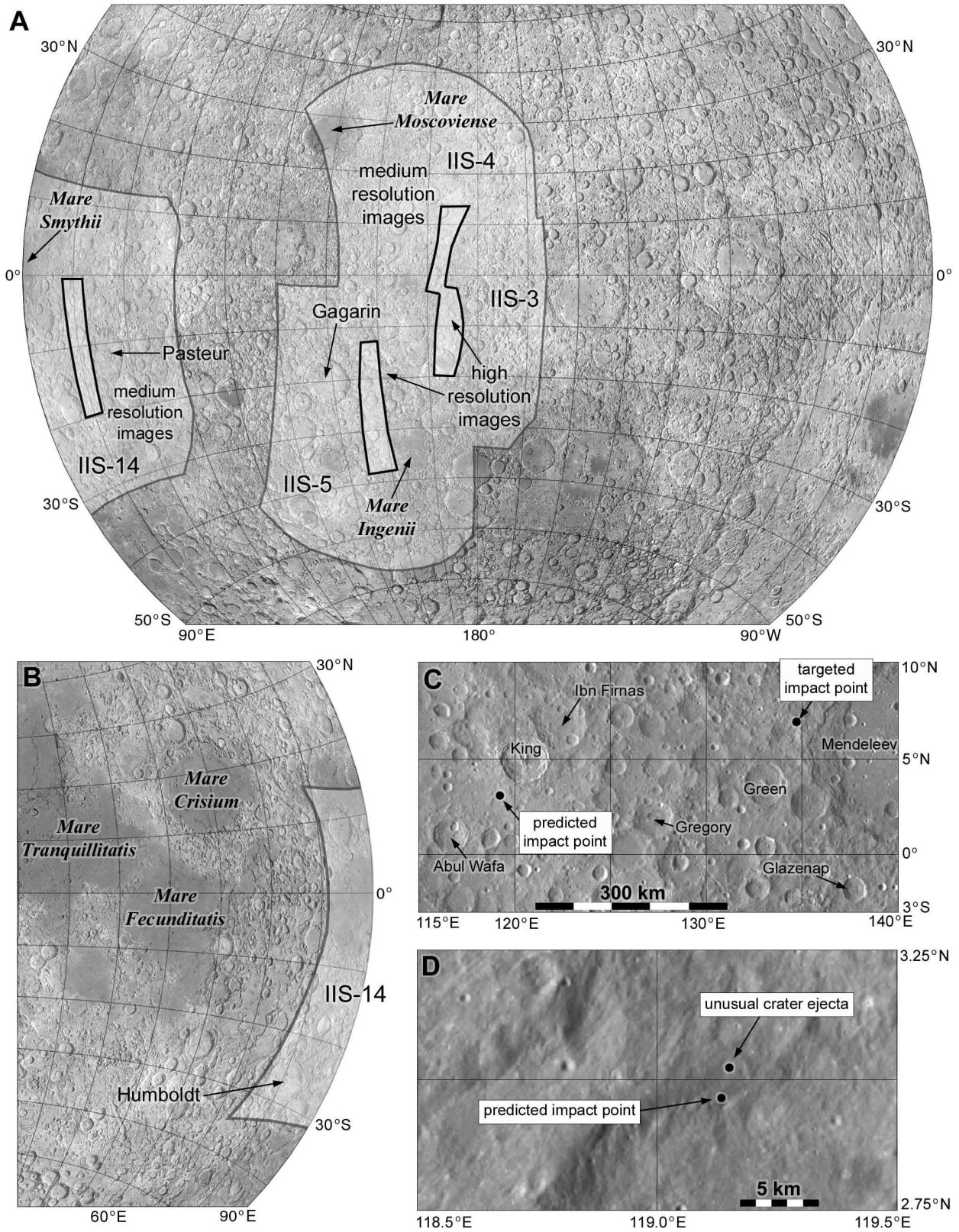


Figure 57. Lunar Orbiter 2 farside image coverage and impact area. A: farside image coverage. B: farside image extension onto the nearside. C and D: impact target and predicted impact site.

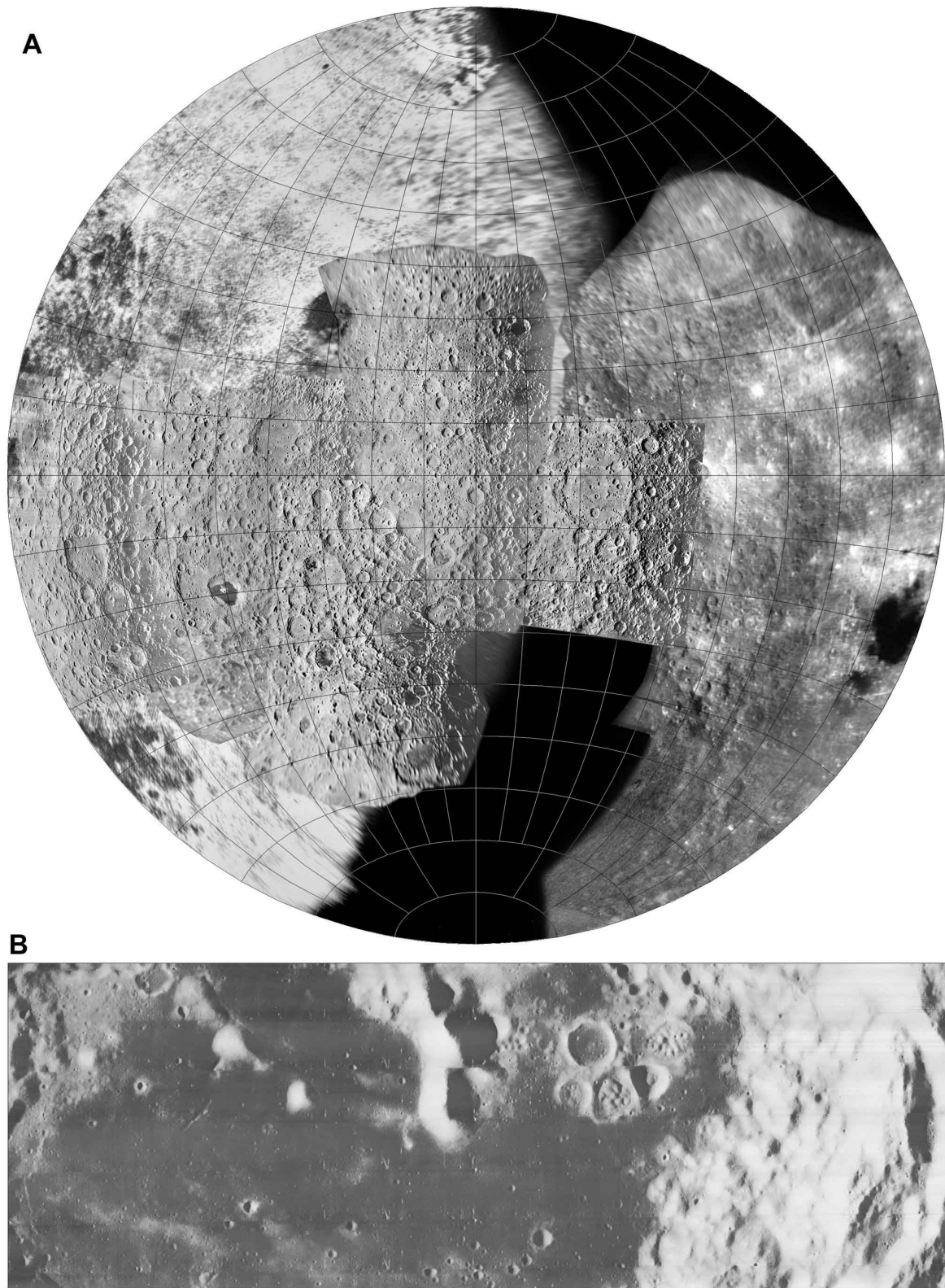


Figure 58: Lunar Orbiter 2 images. A: farside image coverage after the Lunar Orbiter 2 mission. This map follows Figure 52A and the sequence is continued in Figure 72A. B: detail of Lunar Orbiter 2 image II-033-H3 showing dark lava flows and unusual clusters of domes in craters on the floor of Aitken at 17° S, 173° E.

Comparison with Lunar Orbiter 1 farside coverage (Figure 51) shows that these new images extended the earlier coverage and provided a bridge to the nearside. Figure 58 shows the combined farside coverage of all missions up to and including Orbiter 2.

On 8 December 1966 the orbit inclination was increased to 17.5° to extend the latitude range of lunar gravity data. Three meteoroid hits were detected while in lunar orbit. The spacecraft was tracked until it was commanded to impact on the lunar surface. The intention was to impact in the Apollo zone to give tracking data for a nearside impact and to allow the possibility that an Apollo crew might be able to inspect the impact site. This could only be done if the perilune was within the Apollo zone range of longitudes at the time of impact, but it became clear that the spacecraft attitude control fuel would be depleted before perilune reached that region. A de-orbit burn was conducted on 11 October 1967 to target the impact at 6.91° N, 134.64° E. Tracking after the burn suggested impact would occur at 07:13 UT, and at 2.96° N, 119.13° E (Boeing Co., 1967b). LRO imaged an unusual impact crater ejecta blanket at 3.02° N, 119.15° E (Ashley, 2011) which might have marked the Lunar Orbiter 2 crash site (Figure 57C), but the identification was not conclusive and with hindsight does not resemble oblique artificial impact craters. Given the lack of knowledge of topography at the time, the impact site was probably further to the west as the descending spacecraft would strike the high elevation surface earlier than expected.

Ashley, J., 2011. Crash or coincidence? LROC blog post, 20 July 2011, <http://lroc.sese.asu.edu/posts/359>

Boeing Co., 1967a. *Lunar Orbiter II: photographic mission summary*. NASA Contractor Report CR 883, Boeing report D2-100752-1. Seattle, Washington: Boeing Co.

Boeing Co., 1967b. *Lunar Orbiter II: extended mission spacecraft operations and subsystem performance*. NASA Contractor Report CR 1141, Boeing report D2-100752-4. Seattle, Washington: Boeing Co.

Hansen, T. P., 1970. *Guide to Lunar Orbiter Photographs*. NASA SP-242. Washington, D. C., National Aeronautics and Space Administration.



1966: Lunar Orbiter 2 Site Screening

Lunar Orbiter 2 provided excellent high resolution images for Apollo site selection work, and the procedure described for Lunar Orbiter 1 could now be fully implemented. Figure 59 shows all candidate landing sites (ellipses) identified on Orbiter 2 images. The sites preferred after detailed screening are shown in black. The white ellipses were too rough or had poor approach paths.

Site IIP-4 was too rugged for landing and is not illustrated here as it was rejected before screening. The word site was used both for Orbiter imaging sites and candidate landing ellipses, creating potential confusion in the literature of the time (Lunar Orbiter Photo Data Screening Group, 1967).

All ellipses mapped in Figure 59 are 7.9 by 5.3 km, giving an indication of scale for these images. The differing apparent sizes of the ellipses reflect the different sizes of the Orbiter sites, which are adjusted here to fit onto the page. Faint lines extending eastwards from the black ellipses show the range of possible approach azimuths.

Lunar Orbiter Photo Data Screening Group, 1967. *Preliminary geologic evaluation and Apollo landing analysis of areas photographed by Lunar Orbiter II*, Langley Working Paper LWP-363, March 1967.



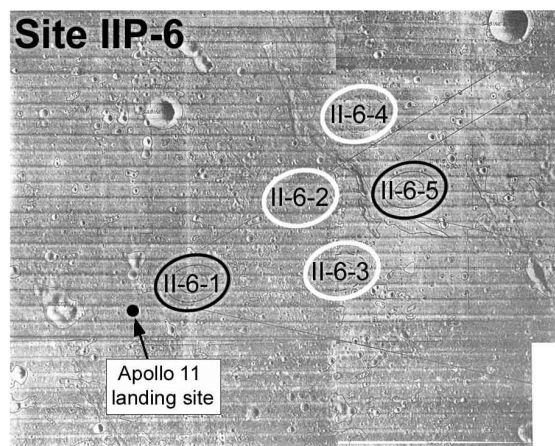
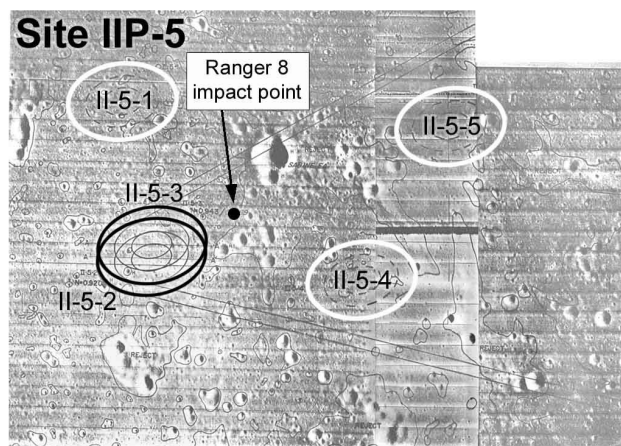
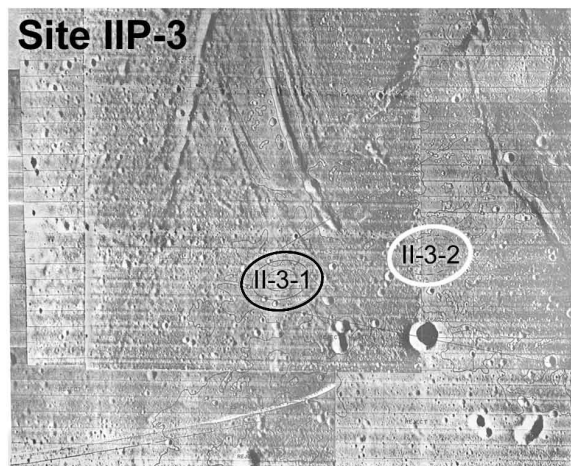
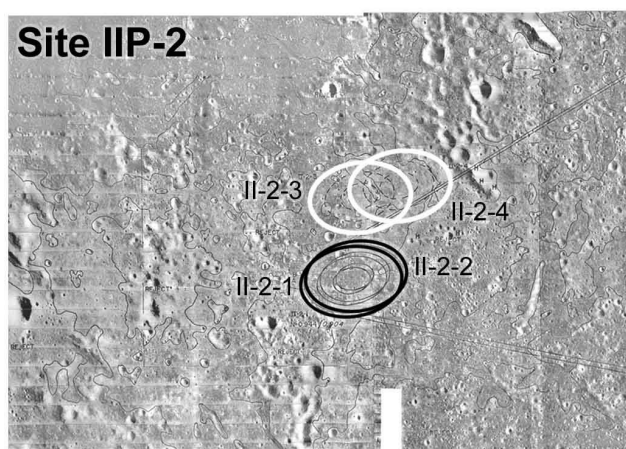
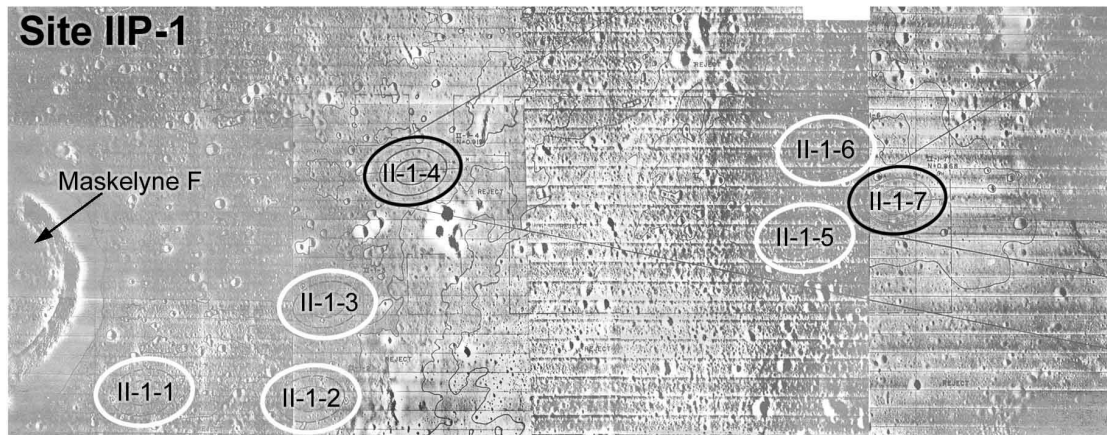
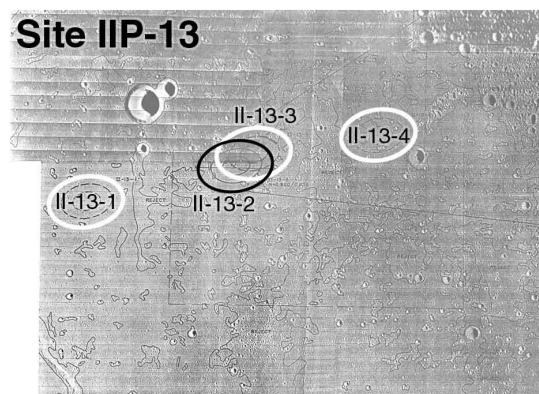
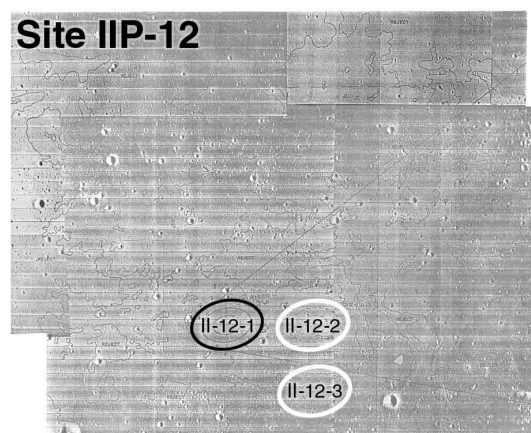
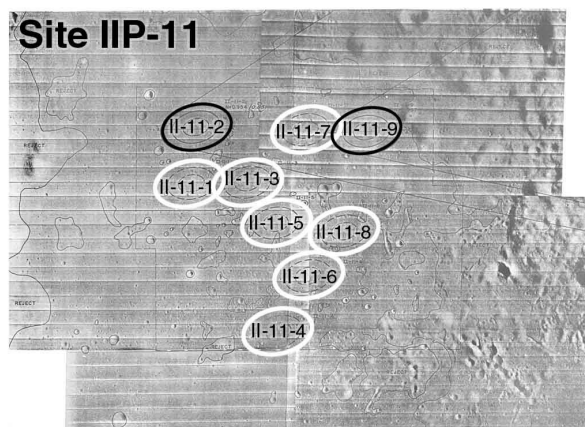
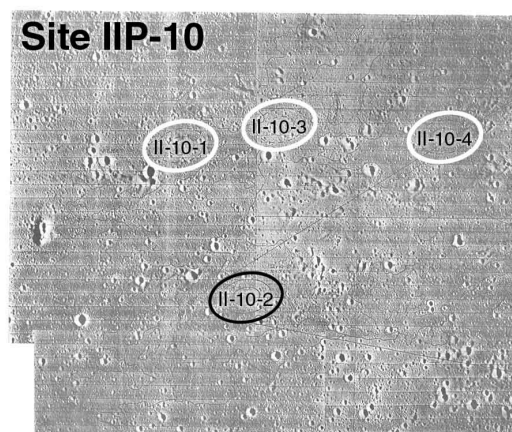
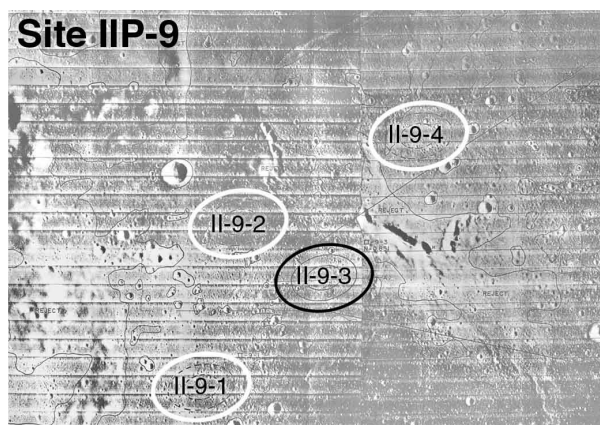
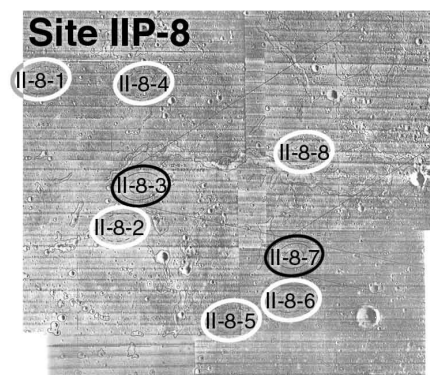
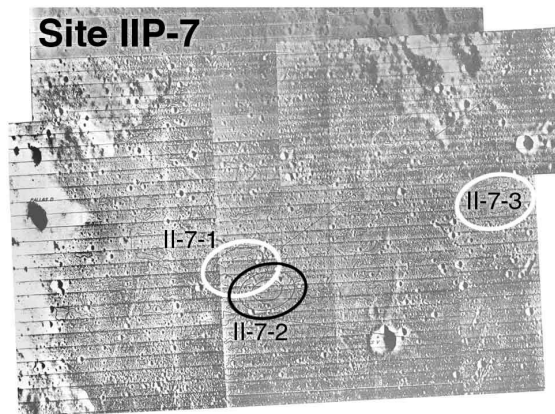


Figure 59 (both pages): Lunar Orbiter 2 site screening results (Lunar Orbiter Photo Data Screening Group, 1967a). Scale is indicated by the ellipses, which are 7.9 km long and 5.3 km wide. An enlargement of ellipse II-5-3 in Site IIP-5 is shown in Figure 87C.



1966: Advanced Exploration Studies

Planning for Apollo was now advancing rapidly, but what would follow the first few landings? Many people assumed that Apollo was merely the start of a long exploration program, perhaps even leading to human expeditions to Mars and other deep space targets but certainly including many years of lunar exploration with ever-growing capabilities. Several advanced exploration concepts were developed by aerospace companies and researchers in 1966, often using different terminology but with many common characteristics.

Elston and Titley (1966) laid out a decade-long exploration plan drawing on the Woods Hole, Falmouth and OSSA studies illustrated in Figure 32. They considered Apollo missions with capabilities similar to Apollo 12, extended Apollo missions referred to as Apollo Extension Systems (AES) which might spend nearly 2 weeks on the surface using a pre-landed shelter and a small rover, long traverse missions with stay times of up to 6 months using sophisticated mobile laboratories, and a permanent lunar base. The plan is summarized in Table 16 and illustrated in Figure 60.

Only three Apollo landings would be flown, all in one year, to relatively simple sites in Sinus Medii, Mare Tranquillitatis and Ptolemaeus. An alternative to Sinus Medii would be a mare surface further west crossed by rays from the crater Copernicus. Four advanced lunar orbiters would then map the entire lunar surface over the course of three years. Overlapping them in time, five AES missions would be flown at roughly annual intervals to more advanced sites including Alphonsus and a farside mission to an unspecified location. These might be augmented by three more AES flights to one of the poles, to the Marius Hills and to Aristarchus, which were more challenging targets.

Year	Mission	Location	Notes
1	Apollo 1	Sinus Medii	First landing. Alternative: mare site further west with Copernicus rays
	Apollo 2	M. Tranquillitatis	Second landing. Mare surface
	Lunar Orbiter		Begin global mapping
	Apollo 3	Ptolemaeus	Third landing. Upland plains (Cayley Formation), possibly volcanic
2	AES 1	Hyginus Rille	SW rim of Hyginus crater. Ash, wall stratigraphy, Imbrium ejecta
	Lunar Orbiter		Continue global mapping
3	AES 2	Alphonsus	Walls, plains, rilles, vents, central ridge and peak, Kozyrev's gas emission
	Lunar Orbiter		Continue global mapping
4	AES 3	Hadley Rille	Apennine mountain material, source vent of rille, basin rim structure
	AES 4	Censorinus C	Highlands, ancient plains units, fractures, crater chains
	Lunar Orbiter		Complete global mapping
5	AES 5	Farside	Site to be located in Lunar Orbiter images
6	Traverse T1	Central highlands	Sinus Medii, traverses to highlands, Hipparchus and Albategnius
7	AES 6 (?)	South pole	Permanent shadow areas, possible ice deposits
	Traverse T2	Copernicus	Land south of crater, traverses to Mare Imbrium and highlands to east
8	AES 7 (?)	Aristarchus	Young impact crater, volcanic plateau, reported gas eruption at Cobra Head
	Traverse T3	Colombo/Nectaris	Land near Mädler, traverses to Theophilus, Mare Nectaris, Colombo
9	AES 8 (?)	Marius Hills	Young volcanic complex, mare region
	Traverse 4	Palus Somnii	Land near Proclus, traverses to Crisium, Taurus Montes, Fecunditatis
10	Lunar Base	Mare Orientale	Youngest large impact basin, astronomy and radio astronomy sites. Long traverses from the base could reach Gassendi and Mare Humorum

There would be four long traverse missions, each lasting six months and launching at yearly intervals. These would follow looping paths (Figure 60) through the central highlands, the Copernicus region, the Nectaris region and Palus

Somnii. These were not planned in detail and the illustration is only suggestive, but each might involve multiple landings to set up and to cache supplies along the traverse routes. Finally a base would be established, probably near the western limb in the Orientale basin, south of the equator so telescopes could survey the Magellanic Clouds, near the radio-quiet far side where a radio telescope might be set up, and in a spectacular and geologically intriguing young impact basin. The illustration suggested Lacus Veris as a suitable base site. Long traverses from the base could reach as far as Gassendi and Mare Humorum. The first traverse started at the first Apollo landing site in Sinus Medii.

Elston, D. P. and Titley, S. R., 1966. Manned exploration of the lunar surface. *Annals of the New York Academy of Sciences*, v. 140, no.1, pp. 636-646.



1966: Extended Exploration Planning

While the first landing sites were being sought in Orbiter images, planning continued for larger scale lunar operations. NASA's Lunar Exploration Working Group (LEWG), set up in February 1966, prepared a detailed plan (NASA, 1966) involving robotic and human exploration including long 90 day traverses in a large pressurized rover called MOBEX (Mobile Excursion Vehicle). This plan has many similarities with the Elston and Titley (1966) study. The sequence would begin with three Apollo landings in 1968 and 1969. Then five advanced Lunar Orbiters would photograph the entire Moon, and ten advanced Surveyors, possibly carrying rovers, would land between 1970 and 1975. Three more Orbiters with advanced instruments would map surface composition, possibly on film to be retrieved by a crew in an Apollo CSM.

During this period, advanced Apollo landings would continue in a program called Saturn-Apollo Applications (SAA). Once a year, two Saturn Vs would be launched, one with a remote-controlled LM carrying supplies, the second with the landing crew and a smaller rover called the Local Scientific Survey Module (LSSM). The pre-landed LM would serve as a shelter for the crew. The surface missions would last for 14 days, using the LSSM to explore within 8 km of the landing site at five SAA sites (Figure 61A-61E). Figure 61F shows surface operations at an SAA site near the crater Moltke B, and also indicates the level of image detail available at the time for these studies, which were done before Lunar Orbiter images became available. The crew would use an LSSM rover to visit three sampling objectives, each 8 km from the landing site, on three separate excursions during a 14 day stay. The next stage involved three expeditions using the MOBEX rover on long traverses (candidate routes are shown in Figure 61G). Finally, six month stays in temporary stations, using wholly redesigned vehicles and a crew of six, would be undertaken during the late 1970s as a prelude to the development of a permanent lunar base.

The five SAA sites are Moltke B (1), the Ranger 8 site (2), Hyginus (3), a site southwest of Kepler crater with two mare surfaces of different ages (4) and a highland site, Capella M (5). Some of the sites are shown in more detail in Figure 62. The report suggested landings in the order 2, 1, 3, 4, 5. The MOBEX routes allow sampling of many types of material during 90 day excursions, some of which linked the SAA sites. Locations for sampling and instrument deployment are shown as dots along the traverses. The set of three looping traverses between Copernicus and Aristarchus was referred to as the Northwest Cloverleaf.

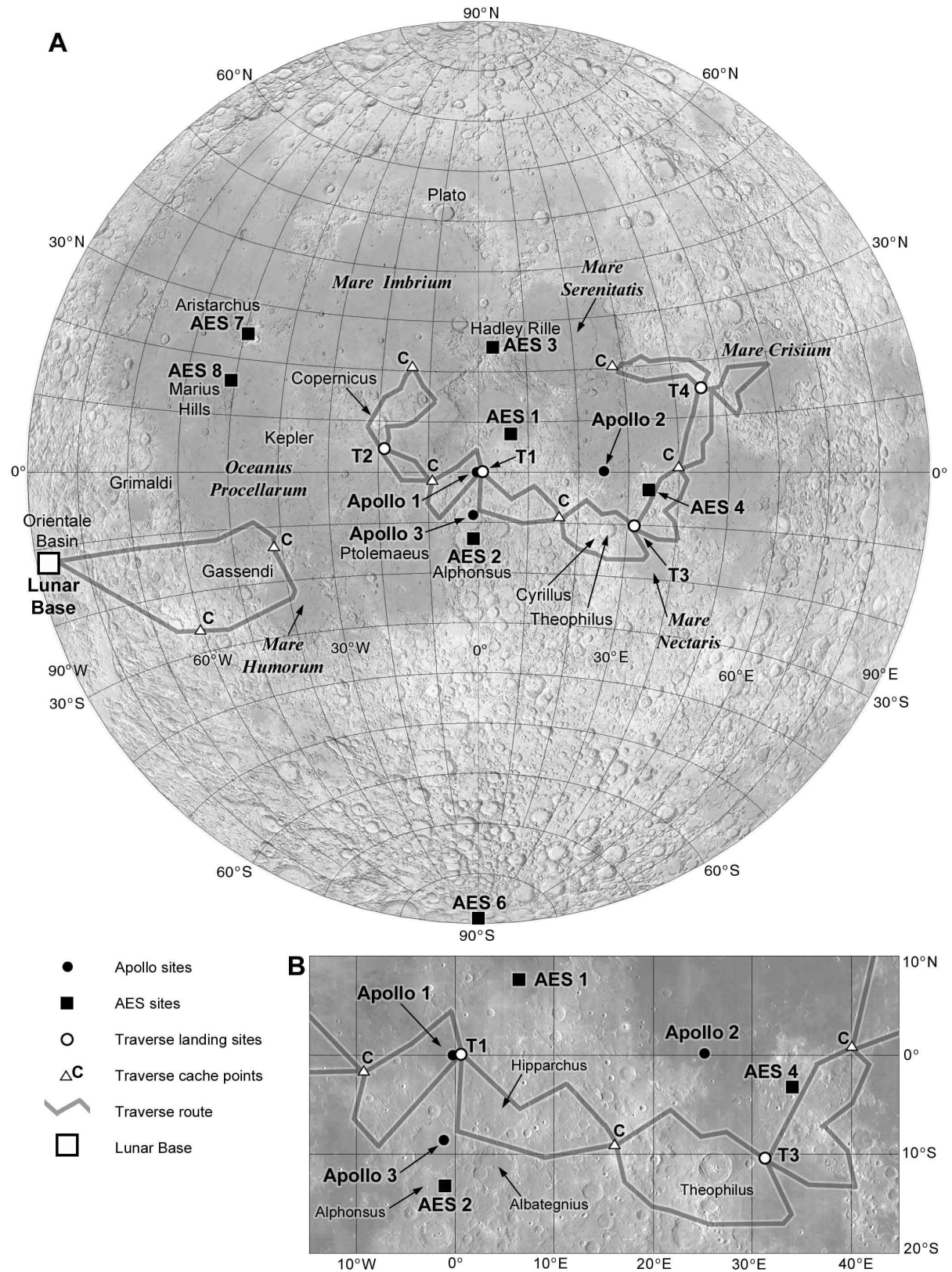


Figure 60. The exploration plan outlined by Elston and Titley (1966). A: global plan. AES 5 would be sent to the Farside. B: details of the central part of the nearside.

The Aerospace Systems Division of Bendix Corporation (1966) conducted a study of rover navigation during exploration of a region surrounding a landing site. The study assumed that after a few simple Apollo landings a more advanced project, the Apollo Applications Program (AAP) would use modified Apollo hardware to accomplish much more exploration. AAP was essentially the same as AES and SAA described above. A lunar module flown without a crew would land supplies at the site and serve as a shelter when the crew arrived. It would deliver a rover (LSSM) as well as food, water and equipment. The study included assessments of the visibility of the shelter from a distance and the ability to maintain line of sight communications at the four sites illustrated in Figure 62 and listed in Table 17. It made use of the LAC and AIC topographic maps available at the time, augmented with Ranger images. A fifth analysis was based on a fictitious location on the farside, before any useful images had been obtained by the Lunar Orbiters.

Table 17. Bendix Corporation (1966) LSSM Rover Study Sites		
Name	Location	Notes
Alphonsus	12° 13' S, 1° 40' W	The Ranger 9 site was used in this report rather than the Ranger 8 SAA site (old atlas, MOBEX-SAA plans)
Capella M	4° 20' S, 36° 38' E	Rilles and a dome west of Capella M, highland site
Moltke B	1° 20' S, 25° 26' E	Mare surface adjacent to highlands, with craters, rille and dome
Hyginus Rille	7° 45' N, 6° 43' E	Large rille and crater chain complex, Fra Mauro Formation
Note: The coordinates of the Alphonsus location are given incorrectly in the source but are corrected here.		

The Bendix sites were based on the locations described above (Figure 61), but with some differences. Capella M, Moltke B and Hyginus were SAA sites. The SAA plan included the Ranger 8 site, but because Ranger 8 approached the surface at a low angle the spacecraft had not imaged its impact site. Bendix substituted Ranger 9 for their study because its image coverage did include the impact site. The SAA site near Kepler was omitted and a fictitious farside site was examined in its place to determine the requirements for farside exploration.

LSSM traverses were mapped to simulate a comprehensive exploration program at each site, including geological sampling, seismic surveys and drilling operations. They are reproduced from the original document in Figure 62, but some are a poor fit to real topography because of the resolution limitations of the contemporary data used before Lunar Orbiter images were available. The Alphonsus traverses were mapped on a Ranger 9 image without correction for oblique viewing or topography.

Alphonsus traverses would reach up onto the crater wall, including a level-floored depression which had been partly filled with impact melt at the time of the Alphonsus impact. Other routes would visit the complex landscape of dark halo craters and linear rilles (valleys or fractures). At Capella M craters and fractures were the main targets. The volcanic crater Hyginus and other pits and craters strung along the Hyginus Rille would be visited at that site. At Moltke B the traverses crossed the mare surface to visit highlands and an old crater, a hill described by Bendix as a dome, a linear rille and the crater Moltke B itself. One traverse was to be targeted at a hypothetical small fresh impact crater if one was suitable placed.

A year later Bendix published a revised version of the Alphonsus plan which simplified the traverse plan and included sophisticated arrays of scientific instruments to be deployed on the lunar surface (Bendix Corporation, 1967). These geophysical and environmental monitoring systems would be installed during multiple excursions from the central landing site and shelters to monitor possible volcanic activity (Figure 62, bottom). In that map **A2** is a large Block II Apollo Lunar Surface Experiment Package (ALSEP), deployed near the landing site. At points labelled **A1** three smaller Block I ALSEPs would be set up to form a geophysical network. A version of these instrument packages was eventually adopted for use on Apollo. Flying traverses at the site would use a small single person Lunar Flying Unit, which was then being contemplated.

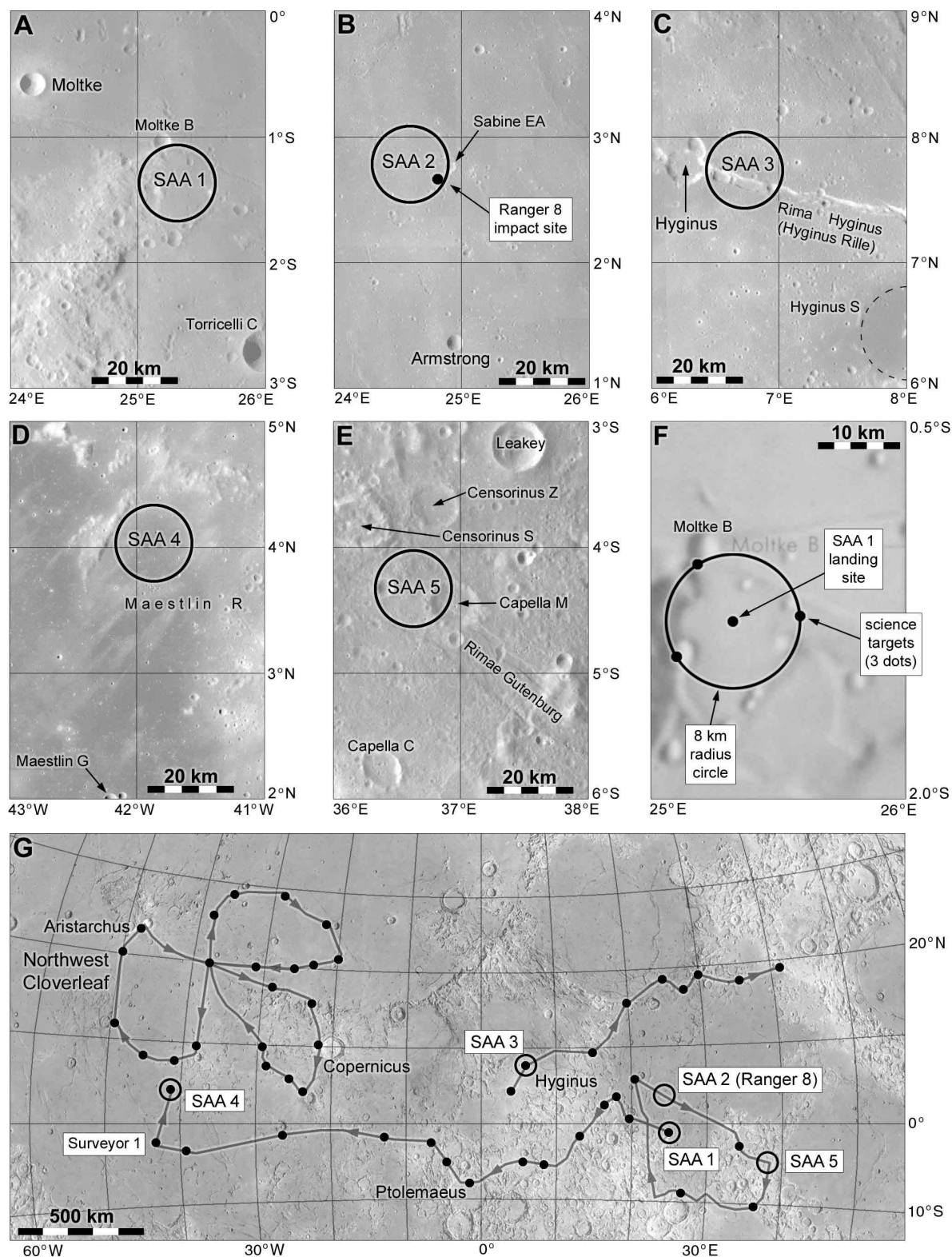


Figure 61. Lunar Exploration Working Group planning (NASA, 1966). A-E: SAA sites. B and D locations are estimated, A, C and E locations are from Figure 62. F: Moltke B site and three science targets from NASA (1966). The map base is the ACIC Ranger 8 Lunar Chart *Hypatia* (RLC 6), original scale 1:1 million, 1st edition, March 1966. G: Long traverses, some linking the SAA sites, from NASA (1966). The dots are sampling sites.

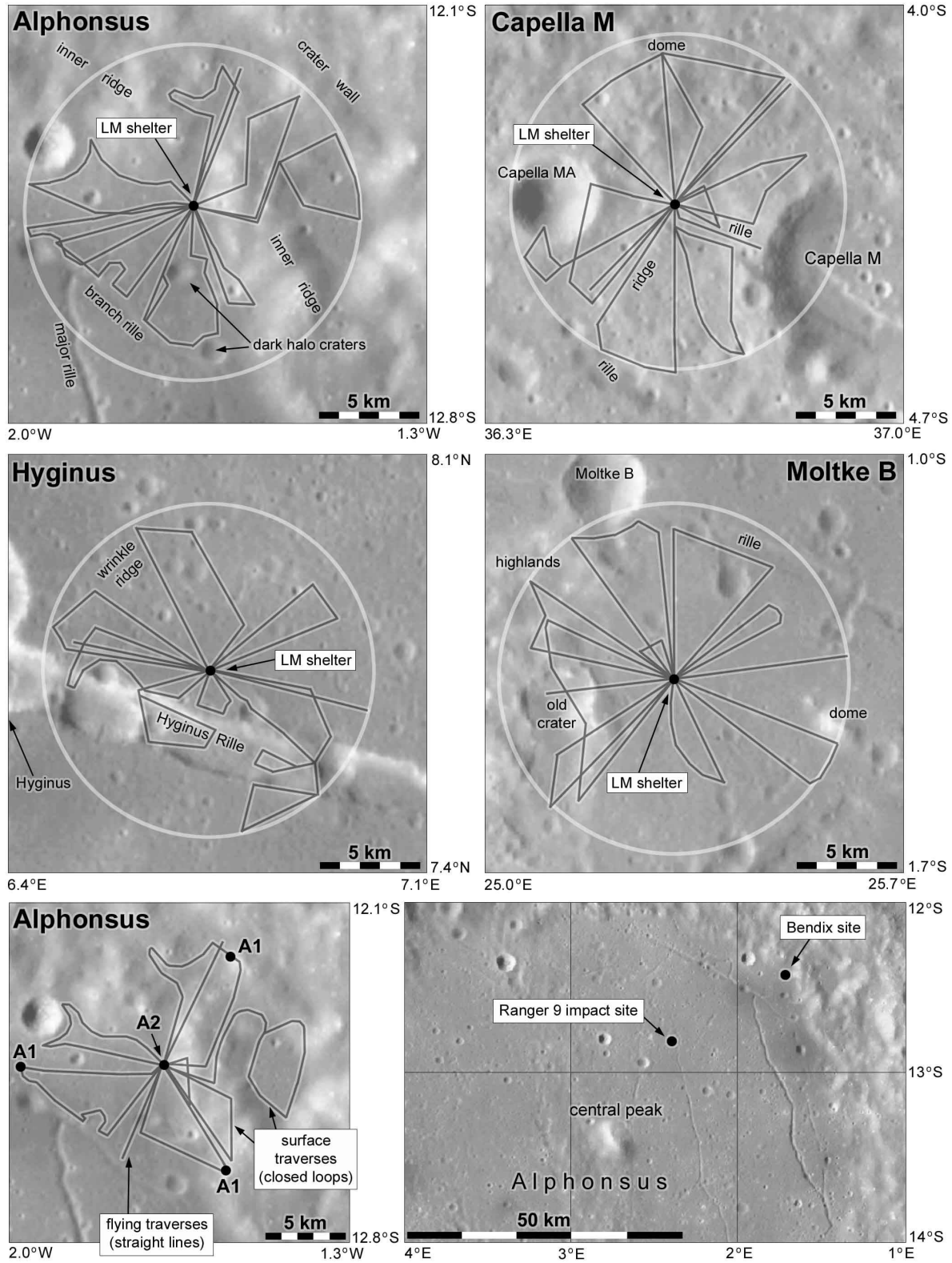


Figure 62. Bendix sites for advanced missions (Bendix Corporation, 1966; 1967). The top four maps are from the 1966 study. At bottom is a different plan for Alphonsus from 1967 with instrument package deployments at the sites labelled A1 and A2. Bottom right: context map showing the Bendix site and Ranger 9.

Bendix Corporation, 1966. *LSSM Navigation Requirements and Techniques*. Report BSR-1239, 19 January 1966. Ann Arbor, Michigan: Bendix Corporation.

Bendix Corporation, 1967. *Lunar exploration considerations*. Un-numbered Bendix report dated January 1967. Ann Arbor, Michigan: Bendix Corporation.

Elston, D. P. and Titley, S. R., 1966. Manned exploration of the lunar surface. *Annals of the New York Academy of Sciences*, v. 140, no.1, pp. 636-646.

NASA 1966. *Lunar Exploration Program Plan*. Lunar Exploration Working Group internal report, 1 November 1966. Washington, D. C.: National Aeronautics and Space Administration.



15 December 1966: Apollo Site Selection Board

This was the first meeting of the Apollo Site Selection Board at which Lunar Orbiter images could be used for detailed site analysis. A procedure was put in place to shape the Board's deliberations over the next two years. A 'reservoir' of about thirty sites would be established, consisting of the Lunar Orbiter prime sites and a list of candidate Surveyor sites (Table 18). This would form Set A, the 'potential sites', initially chosen from telescopic data but now capable of being scrutinised in detail in the new high resolution images.

Table 18. ASSB Set A, potential sites, 1 June 1966.

Lunar Orbiter 1	Lunar Orbiter 2	Lunar Orbiter 3	Surveyor
		(to be selected)	
0° 50' S, 42° 20' E *	4° 10' N, 36° 55' E		3° 20' N, 43° 55' W
0° 10' S, 36° 00' E	2° 45' N, 34° 00' E *		2° 20' S, 43° 50' W
0° 20' N, 24° 50' E *	4° 20' N, 21° 20' E		1° 30' S, 41° 55' W
0° 00', 12° 50' E	4° 45' N, 15° 45' E		0° 30' S, 39° 10' W
0° 25' S, 1° 20' (25') W	2° 36' N, 24° 48' E *		3° 50' S, 37° 00' W
4° 00' S, 2° 50' W	0° 45' N, 24° 10' E *		2° 25' N, 34° 55' W
3° 45' S, 22° 45' W *	2° 10' N, 2° 00' W		3° 05' N, 28° 20' W
3° 00' (36') S, 36° 30' W	0° 05' N, 1° 00' W		4° 30' S, 27° 40' W
3° 15' (21') S, 43° 22' (50') W *	1° 00' N, 13° 00' W		3° 20' S, 25° 10' W
*sites with greatest potential	3° 28' N, 27° 10' W		0° 23' N, 0° 50' W
	0° 05' S, 19° 55' W		3° 20' N, 20° 15' E
	2° 25' N, 34° 40' W		0° 20' N, 21° 30' E
	1° 30' N, 42° 20' W		2° 15' S, 29° 40' E
			0° 25' N, 30° 55' E
			2° 45' N, 34° 00' E
			2° 05' N, 36° 55' E
			2° 45' E, 39° 00' E

From these potential sites a shortlist of about ten 'candidate sites', Set B, would be selected for early mission planning. For an actual mission and specific launch window, one prime and two backup sites would be chosen, forming Set C, the 'selected sites'. Set A locations were to be specified to the nearest degree of latitude and

longitude, or 30 km, and Sets B and C to the nearest minute or 500 m. Despite that statement, from the start Set A was also specified to the nearest minute in Apollo documents.

Backup sites were needed in case a technical problem caused a launch delay. It would take two days to restart the launch process, causing unsatisfactory lighting conditions at the prime site, so a new site would be needed further west. Furthermore, because of the differing accessibility areas at different seasons (Figure 43) it would be necessary to select two sets of three sites for the first mission to ensure that three useable sites were always available. One set would be slightly north of the equator, one set slightly south, with a common site in Sinus Medii which was always accessible. Therefore a minimum of five sites would be selected as Set C.

At this meeting a list of 37 sites was presented as Set A potential sites (Table 18, mapped previously in Figure 49). Exact coordinates differ slightly in different presentations, and some alternate values are included in the table. The likelihood of adding some Lunar Orbiter 3 prime sites to the list was recognized. Sites marked with an asterisk were judged to have the greatest potential at this early stage in the evaluation.

Attention then turned to the Lunar Orbiter images. Apollo planners thought that they could land within an ellipse 5.3 km wide and 7.9 km long to a high degree of certainty, with less certainty that they could land close to the center. Site planners searched for areas of this size with clear approaches and relatively smooth surfaces free of large craters and ridges (Figures 53, 59).

An evaluation of Lunar Orbiter 1 images was presented at this meeting (Table 19). In the nine prime imaging sites, 23 potential 'landing areas' (specific ellipses) were identified. The eight most promising candidates were recommended for more detailed analysis in the priority order indicated in the 'further study' column of Table 19.

Table 19. ASSB: Potential Landing areas Evaluated

Site number	ellipse number	location	further study*	Site number	ellipse number	location	further study*
A-1	1	0.7° S, 42.1° E	no	A-5	1	0.8° N, 2.5° W	no
	2	1.0° S, 42.7° E	3		3	0.7° N, 2.1° W	no
A-2	1	0.7° N, 35.0° E	no	A-6	4	0.2° N, 1.6° W	no
	2	0.5° N, 35.9° E	no		1	3.4° S, 3.9° W	no
A-3	1	0.2° N, 24.5° E	1	A-7	2	3.3° S, 3.8° W	no
	5	0.4° N, 25.1° E	no		1	3.0° S, 23.2° W	8
	9	0.8° N, 26.9° E	5	A-8.1	3	3.2° S, 23.1° W	7
	10	0.5° N, 26.8° E	6		1	3.5° S, 36.2° W	no
A-4	12	0.5° N, 27.6° E	2	A-9.2b	2	3.4° S, 36.8° W	no
	1	0.1° N, 12.8° E	no		1	2.2° S, 44.2° W	4
	2	0.3° S, 12.9° E	no		4	2.5° S, 43.2° W	no
					5	2.6° S, 43.3° W	no

* Numbers in the further study columns give the priority of each site chosen for further analysis

Two other candidates, A-2-1 and A-6-2, seemed favorable in the available Orbiter 1 images, but were thought likely to prove too rough when better images were obtained later. They were omitted from further consideration. 'A' in Table 14 refers to Orbiter mission A (Orbiter 1), not the Set A of Table 18. The use of decimal degrees in some tables and degrees and minutes in others follows the original source documents.



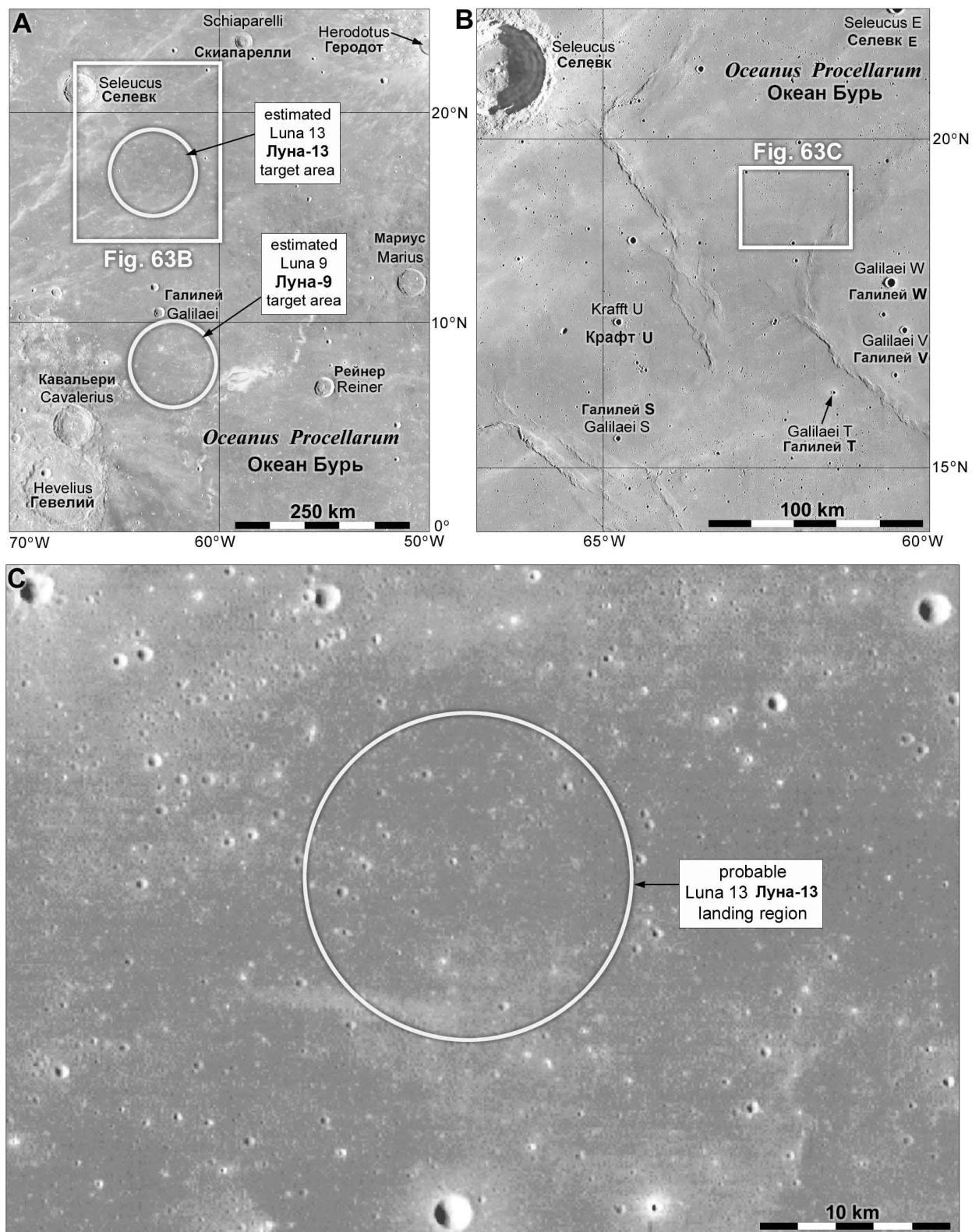


Figure 63. Luna 13 landing site. A: context map. B: the Luna 13 target was the darker, ray-free, mare surface in the centre of B. C: Luna 13 landed in this region. The exact site has not been identified.

21 December 1966: Luna 13

The Soviet Union's second lunar lander was a modified version of the Luna 9 lander. The 1700 kg spacecraft was launched from Baikonur at 10:19 UT on 21 December 1966 and made a trajectory correction on 22 December. Its 150 kg landing capsule reached the lunar surface on 24 December at 18:01 UT, 6.5 hours before local sunrise, at approximately 19° N, 62° W in Oceanus Procellarum (the often cited position of 18.87° N, 62.05° W is misleadingly precise). The landing sequence was identical to that of Luna 9. The petals of the near-spherical body opened after landing to right the spacecraft and expose the instruments and antennas. Radio transmissions to Earth began four minutes after the landing. On 25 and 26 December the television system transmitted panoramas of the nearby lunar landscape at five different sun angles from 6° to 32°. Each panorama required approximately 100 minutes to transmit. The spacecraft carried two cameras, but it seems that images were obtained from only one of them. The mirrors carried by Luna 9 were omitted. The lander was also equipped with four radiometers, and a soil penetrometer and a gamma-ray instrument which were mounted on two long folding arms to place them on the surface. They obtained data on the mechanical and physical properties of the lunar surface material. Transmissions from the spacecraft ceased on 31 December 1966 (Academy of Sciences of the USSR, 1969.)

The Luna 13 landing area (Figure 63) was a smooth mare region south of the craters Seleucus and Schiaparelli. The target was probably the relatively ray-free dark mare area indicated in Figure 63A. The precise landing site is not known. The best chance to identify it in LRO images would be the pattern of features north of the lander seen in a reprojected panorama (Figure 66).

Five fragmentary panoramas (Academy of Sciences of the USSR, 1969) were taken with a camera which faced downwards to the west, showing the spacecraft shadow cast by the rising sun. The second camera, intended to provide overlapping images for stereoscopic analysis, faced upwards into the sun, and apparently either failed to operate or was damaged by solar glare. No images from it have ever been released. Two of the five panoramas consisted of only small fragments, and the other three each have gaps. The panorama in Figure 64 is a composite view assembled from sections of the five individual panoramas by P. Stooke. They show a surface flatter than the Luna 9 site, scattered with rocks and several fragments of the vehicle which carried it to the Moon. The spacecraft shadow was portrayed shrinking as the sun rose higher, providing some surface topographic information from the shadow positions. The British radio telescope at Jodrell Bank received images from Luna 13 as it had from Luna 9, but did not publish them to avoid annoying the Soviet Academy of Sciences.

A folding arm carrying a gamma ray instrument to determine the bulk density of the soil is visible above on this page. A second folding arm carried a penetrometer instrument, which may be just visible to the right of the second camera at top left in Figure 64. The penetrometer showed that the surface material was granular and at least 5 cm deep, not a pumice-like rock as often suggested previously (Cherkasov *et al.*, 1968).

Figure 65 is a shaded relief representation of a Soviet plan at a scale of 1:40 (Academy of Sciences of the USSR, 1969). Luna 13 landed in a crater roughly eight metres in diameter containing an apparent terrace or concentric inner crater. Figure 65 also shows a triangular impression made by the spacecraft as it rolled and bounced before coming to rest, and several spacecraft fragments, presumably parts of the carrier stage from which the landing capsule was ejected at the moment of contact with the surface. A 'track' indicated on the Soviet map was suggested to have been made by a rolling rock set in motion by an impact. The descent stage and airbags are not visible in surface images.

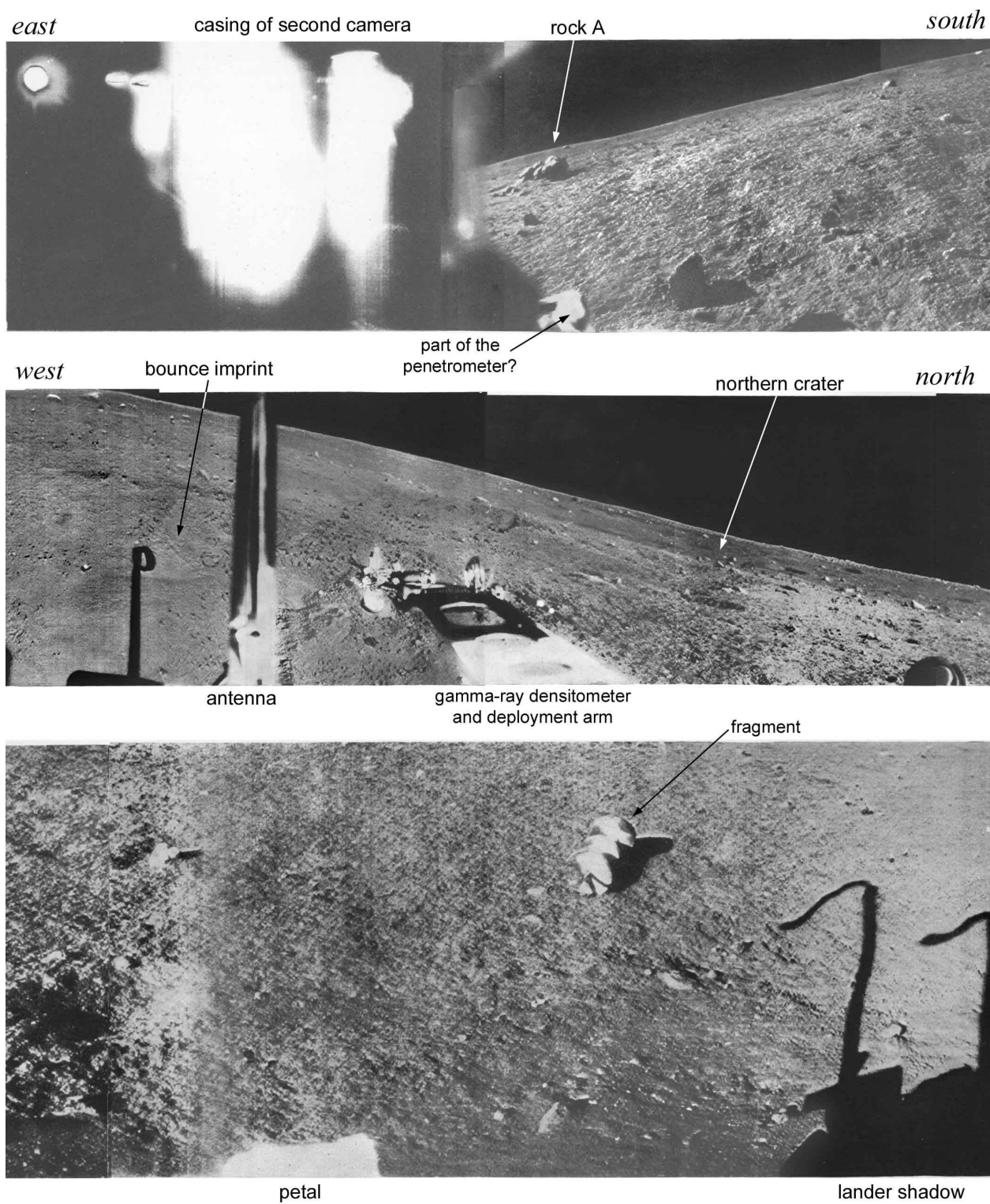
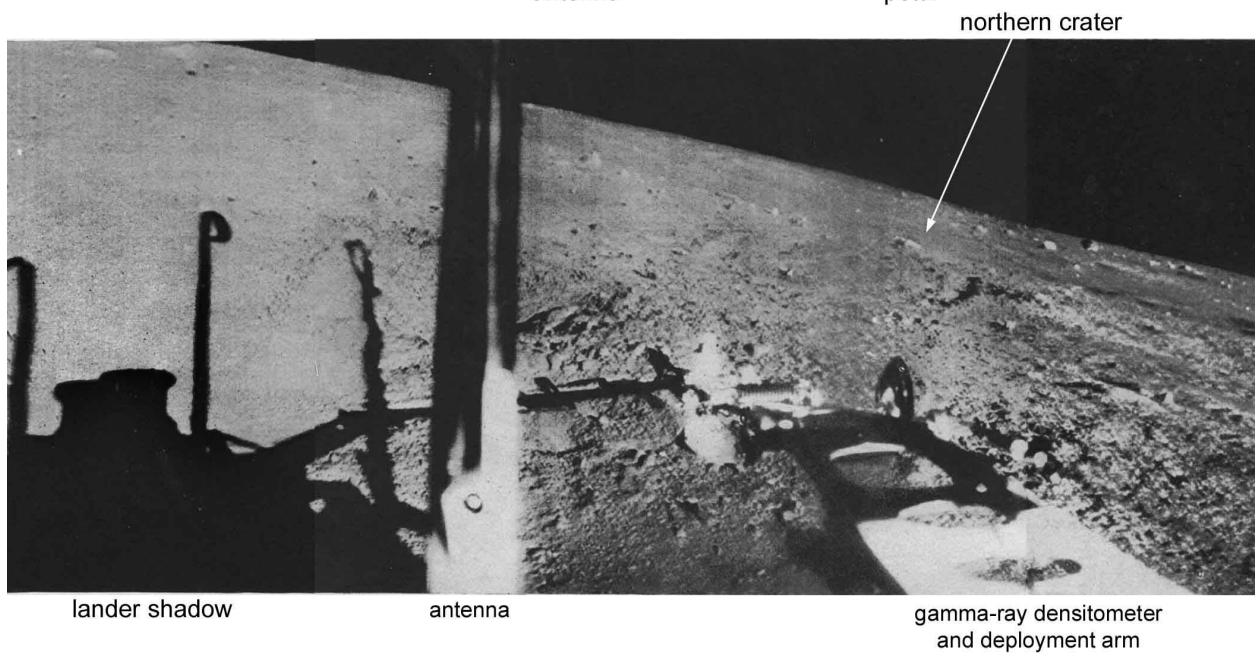
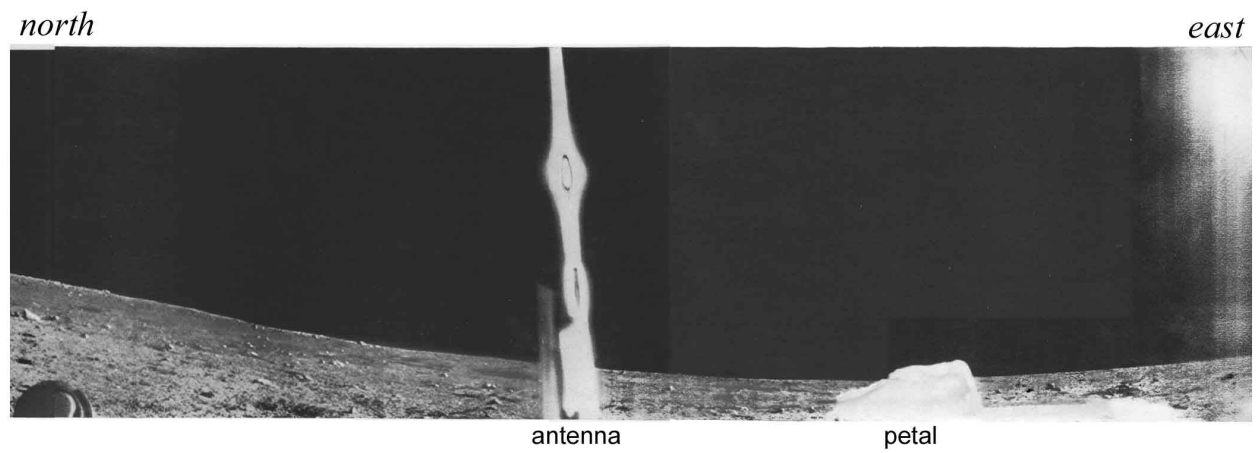
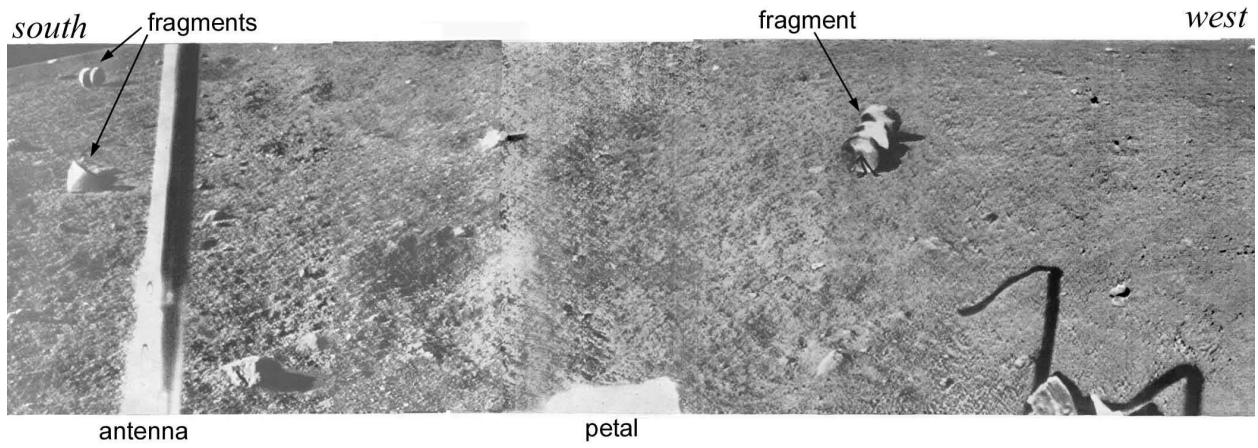


Figure 64 (both pages). Luna 13 panoramas. Top, middle (across both pages): the full panorama. Bottom (across both pages) detail of the central section of the panorama with the Sun at lower elevation, casting longer shadows.



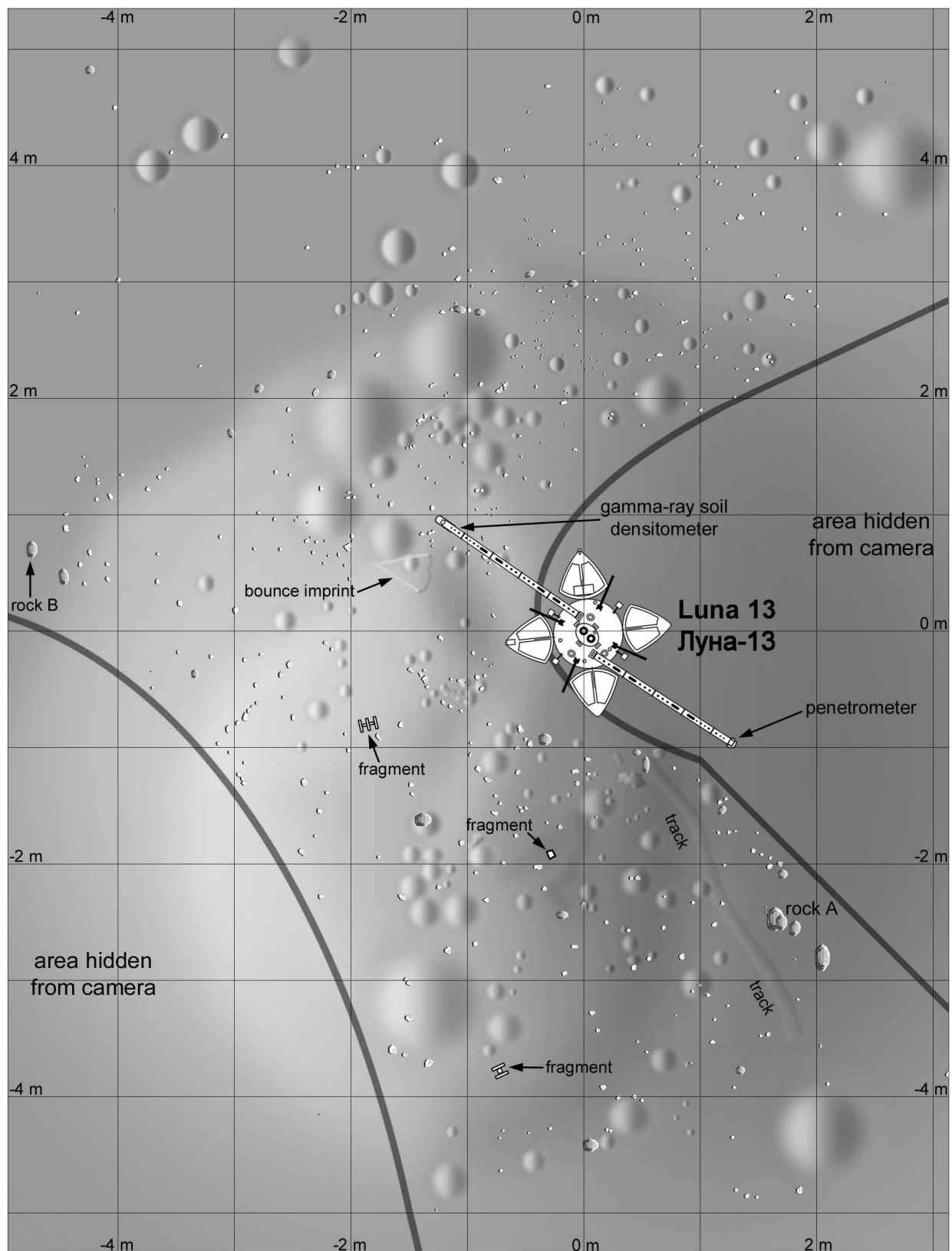


Figure 65. The Luna 13 landing site. A shaded relief drawing by P. Stooke derived from a Soviet map in Academy of Sciences of the USSR (1969).

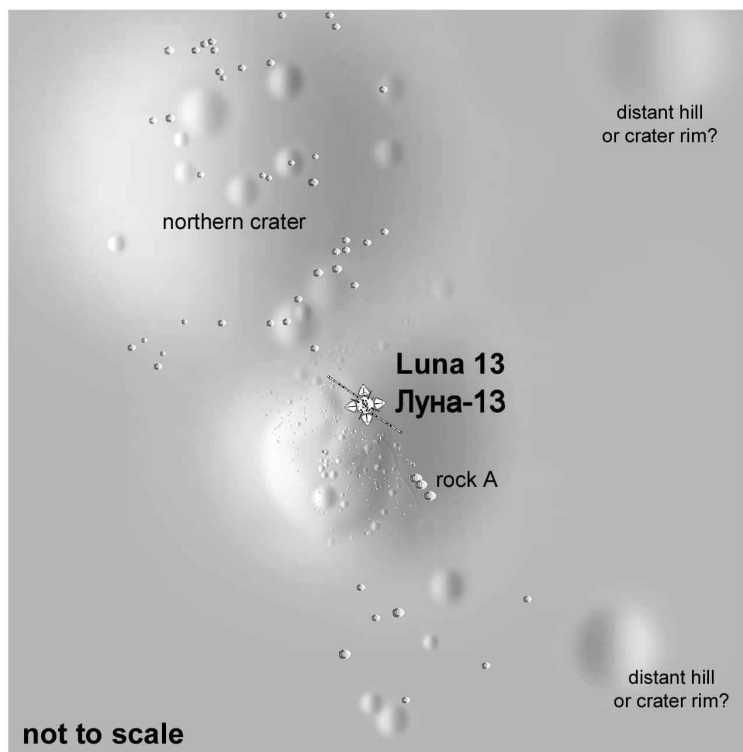
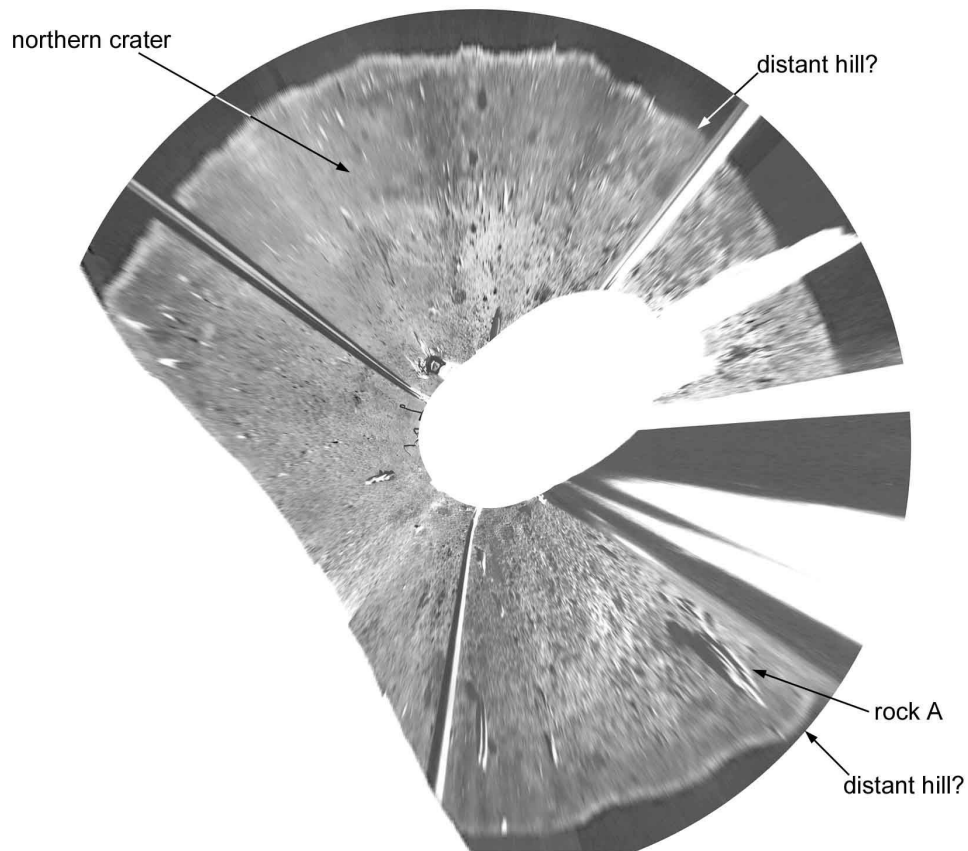


Figure 66. Reprojected Luna 13 panorama and map of surroundings. Sizes and distances of remote objects are very uncertain.

Figure 66 also shows the landing site in a reprojected panorama and a sketch map. The central portion of the map is taken from Figure 65, but features seen near the horizon to the north and south are added schematically. Their true distance cannot be determined. Two very subtle hills or crater rims lie to the northeast and southeast. North of the lander, several rocks appear on the horizon. They must be relatively close to be resolved. Here the area is interpreted as the rim of a shallow crater perhaps 50 to 100 m across.

Academy of Sciences of the USSR, 1969. *First panoramas of the lunar surface, Volume 2*. Moscow: Akademiya Nauk.

Cherkasov, I. I., Mikheev, V. V., Smorodinov, M. I. *et al.*, 1968. Determination of the structural and mechanical properties of the lunar soil by the automatic lunar station “Luna-13”. *Journal of Engineering Physics*, v. 14, pp. 309-311. <https://doi.org/10.1007/BF00828540>



1967: Advanced Mission planning

Planning for post-Apollo missions continued in 1967, and several such plans are summarized here. Bellcomm (1967) analyzed the Apollo Applications Program (AAP), including considerations of the area accessible to AAP and identification of potential landing sites. Ideally AAP should be able to reach any part of the lunar surface, but early missions would be more constrained. This study examined the situation for 1971 missions spending between 5 and 12 days on the surface. The limitations of the spacecraft themselves, especially the ability to change the plane of the orbit to allow the post-landing orbit rendezvous, limited 5 day landings to within 30° of the equator near the centre of the nearside and within 20° near the limbs. This changed to a ‘bow tie’ shaped accessible area for longer missions (Figure 67J, see also Figure 34). Other constraints including communications restricted the latitude extent to within 45° E and 45° W.

The Bellcomm study examined rover planning, taking into account illumination. Visibility of surface relief and hazards was compromised when the Sun was too high, or either in front of or behind the driver. A rover might have to tack, or zig-zag like a sailing ship, to avoid having to drive with the Sun low to the east or west, and landing sites should be chosen to lie north or south of the science targets. Examples of traverses were illustrated at two sites, for a 4 day mission near the central peak of Aphonsus and a 12 day mission in Mare Tranquillitatis near the Hypatia Rilles (Figure 67A, B). Both illustrate the general north-south orientation of traverses. The Apollo 16 traverses in particular satisfied this constraint, and the first two Apollo 15 traverses, but Apollo 17 traverses did not.

Table 20. Landing Sites from the AAP study (Bellcomm, 1967)		
Site	Location	Description
1	2° 55' S, 14° 0' W	Mare Nubium, SW of Turner: domes, craters, rays, mare surface
2	2° 35' S, 30° 45' W	Between Landsberg F and D: craters, wrinkle ridge, rays, mare surface
3	4° 20' N, 4° 40' E	East of Triesnecker: large crater, rilles, crater chain, mare surface
4	4° 45' N, 30° 40' W	Near Hortensius A: crater, crater chain, rays, mare surface
5	4° 15' N, 39° 5' W	Kepler rays: Kepler ray material, mare surface, domes, crater, crater chain
6	1° 30' N, 15° 0' W	Near Gambart: craters, Gambart rim, mare surface, Copernicus rays, dome
7	1° 20' S, 0° 25' W	Oppolzer: Old crater rim, rilles, crater floor material, small craters

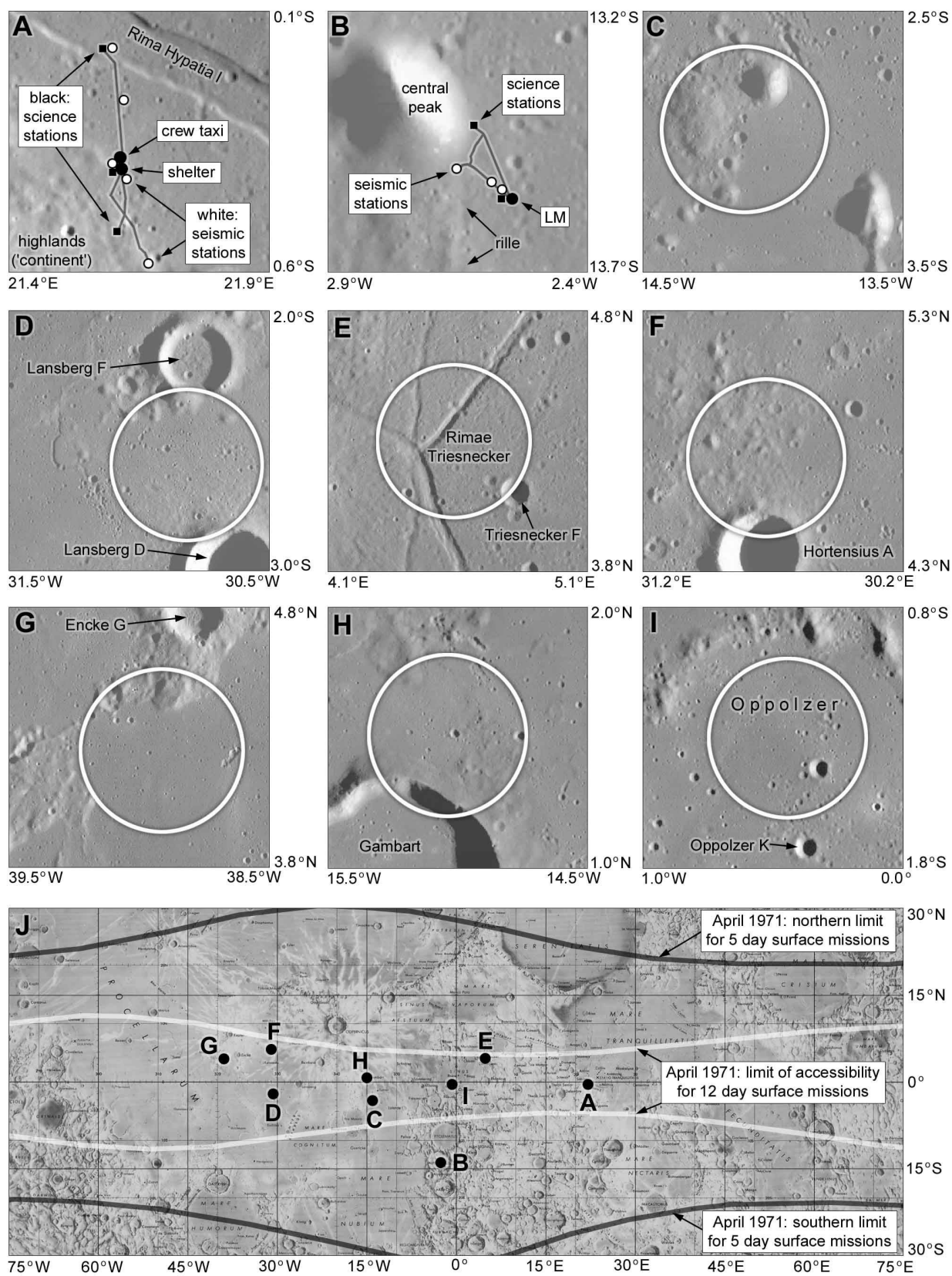


Figure 67. AAP sites from Bellcomm (1967). A-I: individual sites. J: accessibility limits and site locations.

Seven additional locations for landings were identified in an appendix of the report (Table 20). Despite the desire to be able to land anywhere, actual landing regions were expected to be more constrained. The listed sites were all well within the Apollo zone (Figure 34) and many interesting sites including craters Tycho, Copernicus, Aristarchus and even Alphonsus, were excluded. Further technological development might make these locations accessible to AAP, but the report notes that advanced Surveyors could be sent to these locations.

MIMOSA (Mission Modes and System Analysis) was a study by Lockheed Missiles and Space Company for NASA Marshall SFC that developed a very detailed plan for lunar exploration to follow the initial set of six Apollo missions, addressing scientific questions developed at the Woods Hole meeting of 1965. The study examined numerous potential exploration targets, developed several candidate exploration programs using those targets (Lockheed Missiles and Space Company, 1967a), and then recommended three specific programs of varying scope and cost (Lockheed Missiles and Space Company, 1967b). At the largest scales, features the size of the major maria, the study assumed that orbital surveys would be more effective than surface exploration.

Table 21. MIMOSA locales (Lockheed Missiles and Space Company, 1967a)

Locale	Name	Location	Notes
1	Hyginus rille	8° N, 6° E	Rille, volcanic site, deep samples
2	Alphonsus	14° S, 2° W	Old crater, Ranger 9 impact crater, volcanic vents and materials
3	Capella M	4° S, 36° E	Highland-mare boundary, rilles, stratigraphy
4	Hadley's rille	26° N, 3° E	Sinuuous rille, lava flows, Apennine highlands
5	Dark halo craters	6° N*, 17° W	Dark halo craters SE of Copernicus, interpreted as volcanic
6	Aristarchus	25° N, 48° W	Volcanic area, rilles, TLPs
7	Marius Hills	12° N, 53° W	Volcanic area, domes
8	Mare Humorum	20° S, 43° W	Mare bench, old basin rim, tectonics
9	Menelaus Rilles	17° N, 18° E	Dark surface unit, tectonics, lava flows
10	Dome Field	14° N, 36° E	Domes, ridges, lava flows in Mare Tranquillitatis
11	Tycho	43° S, 10° W	Young rayed crater in highlands
12	Mare Orientale	18° S, 94° W	Large fresh impact basin, stratigraphy, impact processes
13	Oceanus Procellarum	2° N, 43° W	Flat region of typical mare, sampling, gravity and magnetic data, seismology
14	Sea of Moscow	25° N*, 150° E*	Farside lavas and highlands at mare boundary
15	Farside	0° N, 180° W	Arbitrary, representative farside highlands region, seismology
16	South Pole	90° S	Possible volatiles in shadows, far from basin ejecta
17	Ranger 8 Site	2.6° N, 24.8° E	Eastern 'blue' mare, Ranger 8 impact crater
18	Straight Wall	22° S, 8° W	Fault scarp, mass wasting processes, may expose stratigraphy
19	SE Serenitatis	22° N, 29° E	Dark mare material, fractures, higher albedo lava flows
20	S. Highlands	45° S, 27° E	Highlands unaffected by basin ejecta, mass wasting processes
21	Grimaldi	7° S, 68° W	Mare surface, relationship to Oceanus Procellarum, astronomy site less affected by Earthshine
22-25			Not defined
26	Moltke B	1° S, 25° E	Crater, rille, mare area, domes, past magnetic fields
27	North Pole	90° N	Possible volatiles in shadows, basin ejecta preserved in original form in cold areas
28	Mare Nubium	15° S, 6° W	Dark, lightly cratered mare region, volcanic features, possible lava tubes to use as shelters
29	Copernicus	9° N, 19° W	Young rayed crater, central peak

* Correcting errors in the source document. The 'Sea of Moscow' site was listed as 45° N, 130° E which is far from any mare-highland boundary.

Table 22. MIMOSA paths and regions (Lockheed Missiles and Space Company, 1967a)	
Path	Notes
a	Mare Imbrium, centre to edge of mare, geophysical traverse, seismic profile, one 300 m deep drill core
b	Mare Imbrium to Mare Serenitatis, edge of Imbrium to centre of Serenitatis, continue geophysical traverse from Path a, basin structure.
c	Palus Putredinis to Mare Vaporum, from start of Path b south to Hyginus, finding a pass up through Apennines, basin structure, crater Conon, volcanic features at Hyginus rille.
d	Mare Vaporum to Mare Tranquillitatis, from Hyginus to 7° N, 21° E in Tranquillitatis, observing mare units, Ariadaeus rille, Julius Caesar rim.
e	Sinus Medii, Hyginus to northern rim of Ptolemaeus, along contact, 300 m drill core and geophysical data collected.
f	Ptolemaeus to Alphonsus, from the northern rim of Ptolemaeus to the eastern floor of Alphonsus. Ancient highland crater rims, volcanic features in Alphonsus.
g	Central Highlands, east from Alphonsus to 17° S, 9° E in highlands, early history, structure, age, composition.
h	Mare Nubium to Straight Wall, Alphonsus to Mare Nubium and Straight Wall, ending at 15° S, 12° W (locale 18), compare this mare to Mare Imbrium.
i	Southern Highlands, east-west traverse centred at 45° S, 21° E, from Janssen to Maurolycus, area remote from basin ejecta, comparisons with farside and mare border areas.
j	Marius Hills to Aristarchus, then to Herodotus T. Volcanic features at Marius Hills and Aristarchus Plateau, Schröter's valley, possible TLPs. Alternatively, Marius Hills to SE Procellarum, volcanic hills and mare lavas.
k	Northern farside, from 28° N, 150° E to Moscoviense Farside mare area, comparison with nearside.
l	Central farside, traverse north from 0° N, 180° W, very ancient terrain.
m	Mare Orientale, traverse across basin, east-west, centred at 18° S, 95° W. Large young unfilled basin.
n	From Copernicus crater to the dark mantle region of Locale 5, impact ejecta deposit, dark halo craters.
o	Mare Humorum, from the rim of Gassendi to highlands at 25° S, 52° W, old mare and basin rim.
p	East-west traverse across Mare Smythii centered at 0° N, 100° E, limb area, particles and fields studies and geology.
q	Traverse across SE Mare Crisium to highland boundary and Auzout domes, WNW-ESE direction, centred at 12° N, 63° E.
r	SE Serenitatis, east-west traverse across mare-highland boundary at 22° N, 30° E, dark mantle area.
s	NW-SE traverse centred at Capella M (4° S, 37° E), faulted highlands and basin ejecta.
t	North pole, traverse along the 10° W and 170° E meridians, centred at the pole, possible volatiles in shadows.
u	Traverse from south pole up the 15° W meridian, possible polar volatiles and highlands remote from basin effects.
Region	Notes
I	Palus Putredinis, survey rim and inner bench of major basin, structural geology, sinuous rille (Rima Hadley), crustal cross-section in Montes Apenninus scarp.
II	Copernicus, impact crater, impact processes, structure, ejecta, region extends from central peaks to beyond the rim.
III	Southern Highlands, cratered terrain far from major basins, age and stratigraphy.
IV	Aristarchus, volcanic features, large rille, possible TLPs.

The sites chosen for surface exploration consisted of up to 29 locales about 10 km across, four regions up to 100 km across and 21 paths or long traverses across the lunar surface. Flight rates during the 1970s of several launches per year, from two to as many as six or even eight, were assumed, with the most complex plans deploying major

astronomical facilities in the prominent mare-filled crater Grimaldi in about 1985. The specific locales, paths and regions used in this study were defined first (Tables 21 and 22).

25 possible lunar exploration programs were presented in this study, compiled using different combinations of the locales and paths described in Tables 21 and 22. They fell into three categories called Programs A, B and C, in order of decreasing cost and complexity (Table 23).

Program A combined lunar exploration with the establishment of X-ray, radio and optical telescopes. The lunar exploration involved 20 paths covering 8500 km and missions to eight locales, with seismic probing to 200 km and 300 m drill cores at five locales. The astronomical facilities would be set up near the end of the program, with two radio telescopes, three optical (ultraviolet) telescopes and one x-ray telescope.

Program B would be similar except that it would involve 11 paths covering 4800 km, seven locales, and three 300 m drill cores. The telescopes would be similar but would include only two optical telescopes. An alternative to Program B, called B', would put more emphasis on different locales, visiting 15 of them and adding only three paths. In addition it would include extensive exploration of two regions, which would themselves include a number of locales and paths not specified in Tables 21 and 22. Three 300 m drill cores would be collected, and the telescopes would be the same as for Program B.

Program C was reduced further in scope, omitting the astronomy component altogether. There would be six paths with a total length of 2400 km and visits to six locales, with two 300 m drill cores. The number of distinct experiments conducted would be about half that of Program A, but still enough to answer the basic questions about the Moon proposed at the Woods hole meeting in 1965. A second version of this, called C', would investigate 13 locales, one region and two paths covering just 200 km, and would collect two 300 m cores.

Table 23. MIMOSA candidate lunar exploration programs		
Program	Components	Specific locales, paths, regions
A	Locales	2, 5, 11, 16, 17, 18, 21 and 26.
	Paths	a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t
B	Locales	2, 5, 17, 18, 21, 26, 28
	Paths	b, c, e, f, h, j, l, m, n, s, u
B'	Locales	1, 2, 3, 4, 6, 7, 11, 12, 15, 16, 17, 20, 21, 26, 28
	Paths	i, j, l
	Regions	I, II
C	Locales	2, 3, 5, 17, 18, 26
	Paths	b, c, j, l, m, u
C'	Locales	1, 2, 3, 4, 6, 7, 12, 15, 16, 17, 20, 26, 29
	Paths	i, j
	Region	I

The study presented numerous versions of these plans with possible mission schedules, but the order of flights to specific sites was flexible and could be varied as needed. Typically the astronomy site in Grimaldi would receive one or two visits early in the 1970s to assess its suitability and then several at the end of the program to set up the telescope infrastructure, with resupply flights as needed to continue operations.

Three recommended programs of lunar exploration were developed from the MIMOSA candidates, Programs I, II and III, again varying in cost and complexity (Table 24). The goal was to extend the capabilities of the Apollo hardware but to keep annual expenditures well below the Apollo funding levels.

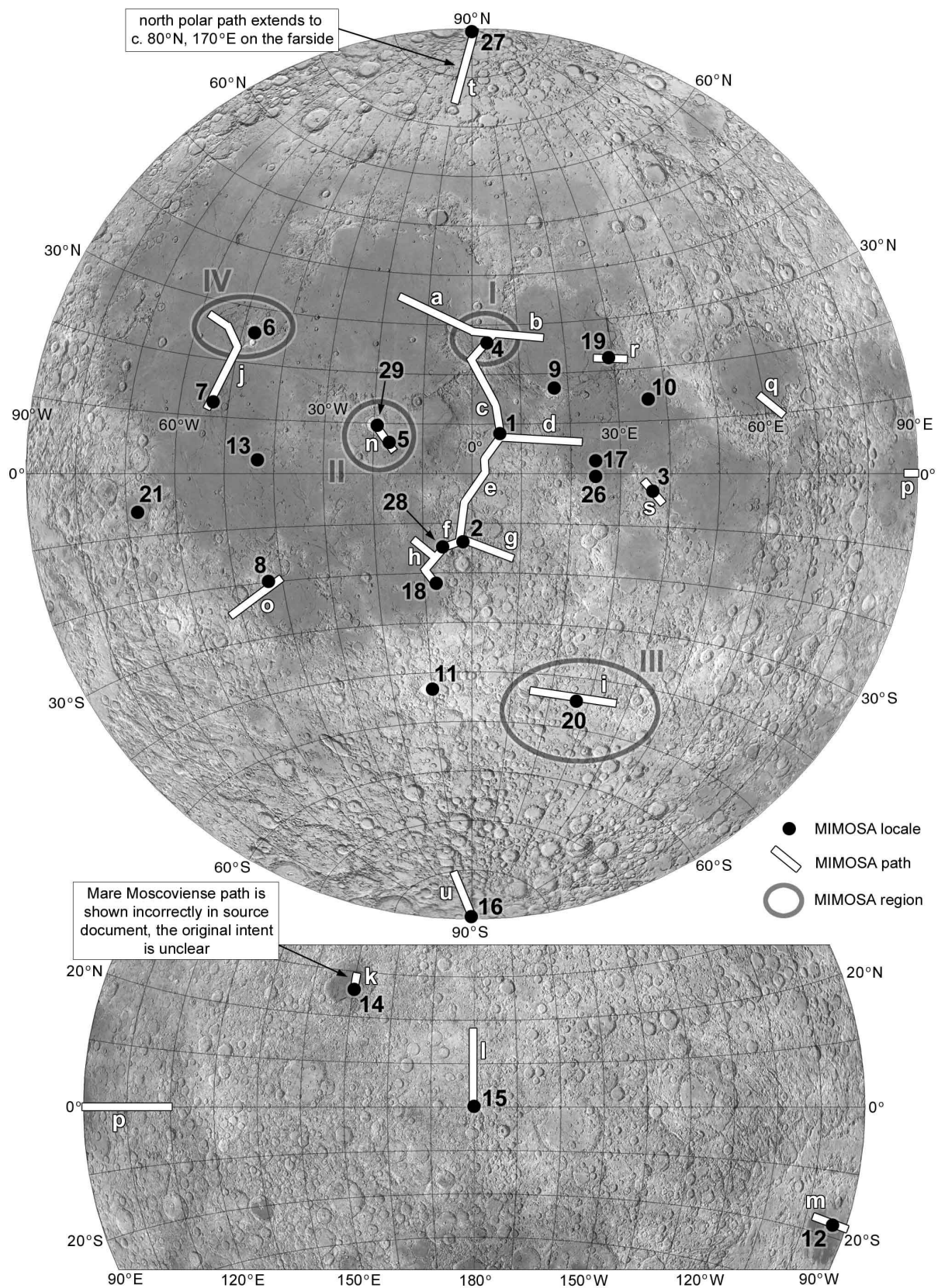


Figure 68. MIMOSA locales, paths and regions from Tables 21 and 22.

Table 24. MIMOSA recommended lunar exploration programs

Mission	Program I		Program II		Program III	
	Year	Notes	Year	Notes	Year	Notes
7	1971	Manned orbiter 1	1971	Manned orbiter 1	1971	Manned orbiter 1
8	1971	Locale 17	1971	Locale 17	1971	Locale 17
9	1972	Manned orbiter 2	1972	Manned orbiter 2	1972	Manned orbiter 2
10	1972	Locale 3	1972	Locale 3	1972	Locale 3
11	1973	Manned orbiter 3	1973	Manned orbiter 3	1973	Manned orbiter 3
12	1973	Locale 13	1973	Locale 13	1973	Locale 13
13	1974	Imaging orbiter 1	1974	Imaging orbiter 1	1974	Imaging orbiter 1
14	1974	Locale 26	1974	Locale 26	1974	Locale 26
15	1975	Imaging orbiter 2	1975	Locale 1	1975	Locale 1
16	1975	Locale 1	1976	Locale 21	1976	Locale 21
17	1976	Locale 21		omitted from list		omitted from list
18	1977	Imaging orbiter 3	1977	Loc. 29, path n	1977	Loc. 29, path n
19	1977	Locale 11	1978	Path d	1978	Path d
20	1978	Imaging orbiter 4	1979	Paths g and h	1979	Paths g and h
21	1978	Locale 29	1979	Imaging orbiter 2	1979	Imaging orbiter 2
22	1979	Imaging orbiter 5	1979	Paths c, e and f	1979	Paths c, e and f
23	1979	Locale 2	1980	Explosives 1	1978*	Explosives 1
24	1980	Locale 4	1980	Explosives 2	1979	Explosives 2
25	1981	Comm. orbiter 1	1980	Imaging orbiter 3	1978*	Imaging orbiter 3
26	1981	Locale 12	1980	Imaging orbiter 4	1979	Imaging orbiter 4
27	1982	Locale 7	1981	Paths a and b	1981	Paths a and b
28	1982	Explosives 1	1981	Explosives 3	1982	Explosives 3
29	1982	Explosives 2	1981	Explosives 4	1982	Explosives 4
30	1982	Imaging orbiter 6	1981	Imaging orbiter 5	1982	Imaging orbiter 5
31	1983	Comm. orbiter 2	1982	Path j	1982	Path j
32	1983	Locale 15	1982	Explosives 5	1982	Explosives 5
33	1984	Locale 16	1982	Imaging orbiter 6	1982	Imaging orbiter 6
34			1983	Comm. orbiter 1	1982	Comm. orbiter 1
35			1983	Locale 21, path m	1983	Locale 21, path m
36			1984	Locale 16, path i	1984	Locale 16, path i
37			1985	Comm. orbiter 2	1984	Comm. orbiter 2
38			1985	Path k	1984	Path k
39			1985	Path l	1985	Locale 21
40			1986	Locale 21	1987	Path l
41			1988*	Locale 27, path t	1986*	Locale 27, path t
42			1987	Locale 21	1986*	Locale 21
43			1989	Locale 21		

Notes: Missions 1 to 6 are the Apollo landings.

Comm: Communications. Explosives: Explosives delivery probe.

Program I would make use of Apollo hardware extended to allow 14 day stays and 30 km of total mobility (maximum range 10 km). Later missions would allow crews to be delivered by one lander and picked up by another to extend stay time and allow access to any location on the Moon. Fourteen locales would be visited in the order listed in Table 24. Three 100 m drill cores would be obtained. The three manned orbiter missions would have

different goals. Mission 1 would probably stay in a near-equatorial orbit to make return flight easier, and would observe the same sites repeatedly, day and night, for photometric and thermal or other studies which could be extrapolated globally. The other two would fly in polar orbits with morning and evening illuminations. The explosive delivery probes would place large explosive charges to create signals for the geophone arrays set out by surface missions, and the exact detonation points of the charges would be identified by before and after imaging by the imaging orbiters.

Program II was to start with the extended Apollo hardware used in Program I, but in the second half of the 1970s new 'medium capability' hardware would be developed to permit longer stays and mobility of up to 1600 km range for a crew of three. The 1980s would feature additional development resulting in a nuclear powered long duration shelter for six people, for use at the astronomical observatory site in Grimaldi. This program included nine locales and 15 paths. Missions 42 and 43 were supplements to mission 40, extending operations at the astronomy site.

Program III followed the Program II pattern closely, with a few modified dates and with expanded capabilities. It assumed that during the 1980s additional development results in a larger lander capable of delivering six people at one time, using a greatly improved Saturn V launcher, and a nuclear powered long duration shelter for 12 people, for use at the astronomical observatory site in Grimaldi. This program also allowed for single optical telescopes to be set up at the south pole and central farside locales to evaluate their potential for future astronomy. Drill cores up to 300 m deep would be obtained at eight locations.

Another study involving an astronomical site in Grimaldi was performed in 1968 at Stanford University and NASA's Ames Research Center (Adams and Billingham, 1969). Like MIMOSA, this 'Moonlab' program was intended to advance both lunar exploration and astronomical research. Grimaldi was chosen for its low southern latitude, allowing a view of the southern sky while also being close enough the equator to simplify orbital operations, and because it offered access to Oceanus Procellarum through gaps in the crater wall for geological traverses. The finished base would consist of eight habitation modules and three large greenhouse modules for growing food. Power would come from solar cells during the day and fuel cells at night. The infrastructure would take fifteen years to build, requiring 37 Saturn 5 launches, and it would be constructed in the northern part of the floor of Grimaldi at 3.5° S, 68.0° W (Figure 69A).

The Moonlab program would begin just after the first Apollo landing. Hardware would be developed from 1970 on, including flying vehicles, rovers and shelters, with a 14-day Apollo flight to certify the site some time between 1971 and 1973. The first shelter, not a modified Lunar Module but a cylinder 8 m high and 6 m across, would be landed in 1976 to support 3 month visits. A storage room above the habitation section would provide extra radiation protection, and this 'Shelter 1' would also be covered with a 1 metre layer of regolith for protection from radiation and micrometeorites. A radio beacon would be deployed to aid future landings.

By 1977 six month stays would be possible and scientific observations would begin. By the next year the crew would increase to six and an exercise, shower and toilet module would be added to the habitat. The crew would increase to 12 and tours of duty would expand to 12 months in 1981, as additional transportation and habitat space was added. The original shelter would be converted to a solar flare shelter. Scientific and agriculture modules would be added in 1982 and 1983, with advanced rovers for distant science traverses. The crew would grow to 18.

In 1984 an observatory module with a 1 metre telescope would be deployed, and three farms would be set up in domes, two of them 18 m in diameter, the third 10 m across. The farms would grow food in processed lunar regolith with a goal of producing 75% of the crew's food needs and recycling carbon dioxide and water. In 1985 the Moonlab crew would reach 24, including 8 dedicated to astronomy. The original shelter from 1976 would now be converted into a medical and biological research facility. A roof would be constructed over the shelters for micrometeorite and thermal protection, and Moonlab would be complete.

Anselmo and Kinney (1967) studied trajectories for early AAP missions, which would extend the Apollo mission capabilities with longer stay times and more dispersed targets. One important constraint on the earlier Apollo trajectories which would have to be relaxed was the free return trajectory, which would automatically return the spacecraft to Earth if it was not braked into lunar orbit. Free return trajectories were later flown on Apollos 8, 10, 11 and 12 and then dropped as this study had anticipated, to make more interesting sites accessible.

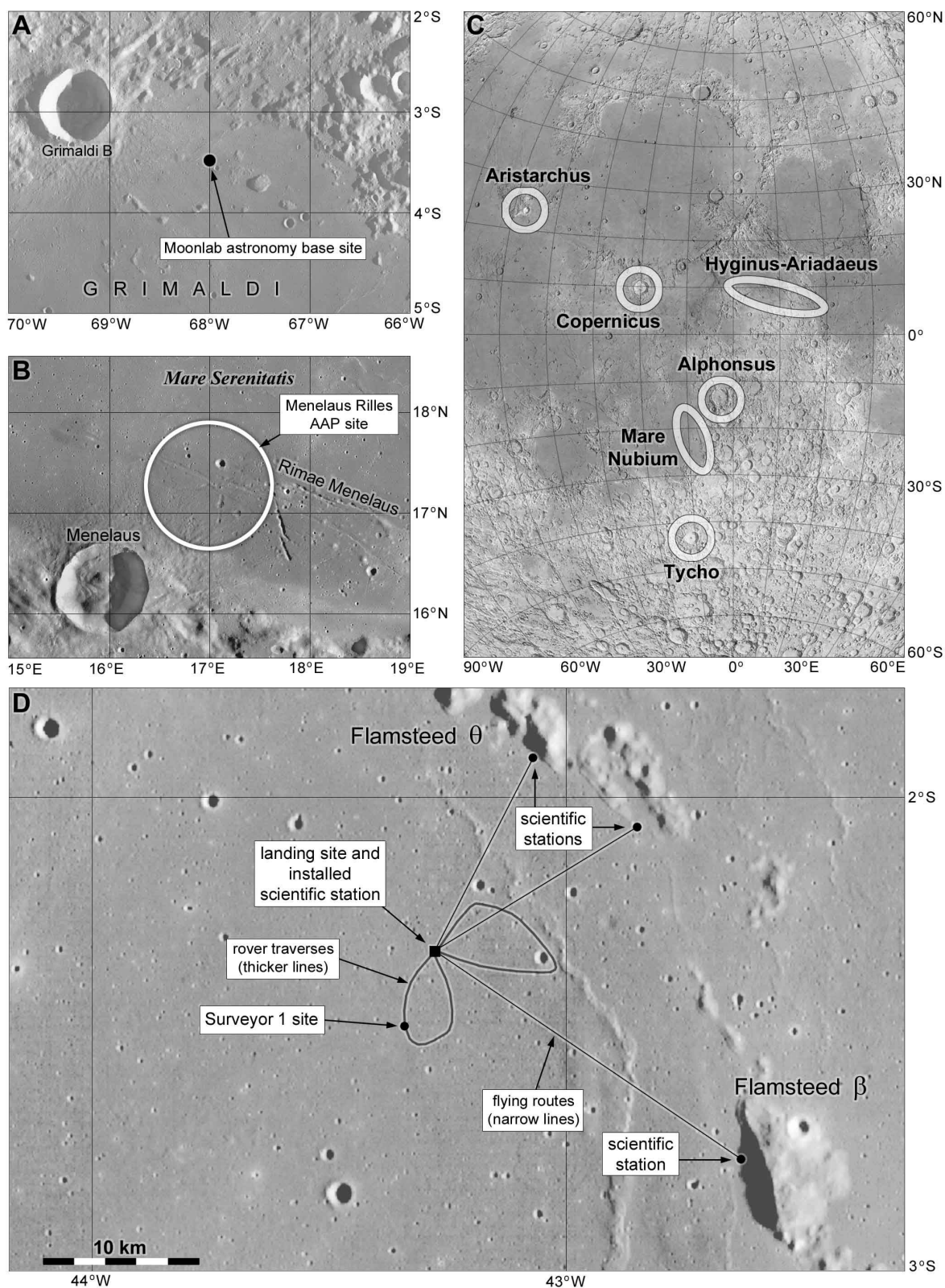


Figure 69. Future mission proposals. A: Grimaldi astronomy site from Adams and Billingham (1969). B: Menelaus Rilles site from Anselmo and Kinney (1967). C: Advanced Surveyor sites from Milwitzky (1967). D: Flamsteed site from Hinners (1967) and Hinners *et al.* (1968). The base for D is LROC image M1169807301.

Five landing sites were examined for their trajectory implications, four for three day landings in 1970 and one (Copernicus) for a six day landing in 1971. The five sites were Marius Hills, Flamsteed Ring, Copernicus floor, Abulfeda and Menelaus Rilles. The last site on the southern edge of Mare Serenitatis was included in the MIMOSA locale list (Table 21) but was rarely mentioned elsewhere and was not covered by high resolution Lunar Orbiter 5 images. It is part of an older fractured mare surface largely covered by later Serenitatis basalts.

MIMOSA and Moonlab were projects on a much larger scale than Apollo, but consideration was also given to modest additions to Apollo. Benjamin Milwitzky, the Surveyor Program Manager at NASA HQ in Washington, argued in favour of a new program of automated landers, building on the success of Surveyor (Milwitzky, 1967). This would augment Apollo by visiting places deemed too dangerous for astronauts. Figure 69C shows six sites he proposed for visits by advanced landers, four major craters and two broad regions of geological interest, the surface of Mare Nubium near the Straight Wall and the mare-highland boundary, and the broad area of tectonically disrupted highland plains around Hyginus and Ariadaeus.

Vaughan (1967), Hinnners (1967) and Hinnners *et al.* (1968) described a mission to Flamsteed P, the ring of hills surrounding both the crater Flamsteed and the Surveyor 1 landing site (Figure 69D). An Extended LM would be able to land within 100 m of its target, carrying 450 kg of equipment including two 70 kg Lunar Flying Units (LFU), one person rocket-powered devices for making short flights to places like hilltops which might otherwise be inaccessible. The Flamsteed mission would include six EVAs. The first would begin with an inspection of the ELM, and the deployment of the large solar panel, and conclude with a short walking traverse to a nearby block field. The astronauts would test communications by moving out of the direct line of sight with the ELM. The second EVA would start with a walk to the foot of the large Flamsteed Ring ridge for sampling, and then up the slope of the ridge to an impact crater 1000 m from the ELM. EVA 3 on day 2 of the mission would begin with extensive testing of the LFUs. Then the Commander would fly to the ALSEP deployment area to select a suitable location while the other astronaut walked to the site, carrying the ALSEP. During EVA 4 one astronaut would fly an LFU up to a ridge crest, then to the foot of the ridge to visit a 'rock moraine' feature (a slump deposit fringing the foot of the ridge), and lastly to the mare surface and an older crater. A core sample would be taken at each stop. The other astronaut would stay near the ELM, sampling and making observations, while also ready to use the other LFU to rescue his colleague if necessary. The fifth EVA, early on the third day on the surface, would take an astronaut to various sites in the mare using the LFU. The other astronaut would work around the ALSEP and remain ready to make a rescue flight if necessary. Finally, EVA 6 would fill in any sampling still to be done, and end with preparations for liftoff.

Adams, J. and Billingham, J., 1969. Moonlab: a design for a semipermanent lunar base. Presented at the 7th Annual Meeting of the Working Group on Extraterrestrial Resources, Denver, 17 to 18 June 1969. NASA TMX-66429.

Anselmo, D. R. and Kinney, W. D., 1967. Lunar AAP Mission Profiles. Bellcomm Technical Memorandum TM-67-2011-1, 29 September 1967. Washington, D. C.: Bellcomm, Inc.

Bellcomm, Inc., 1967. *Apollo Applications Program, Lunar Surface Mission Planning, Volume 2. Supplementary and Detailed Studies.* Military Analysis Center, Bell Telephone Laboratories, November 1, 1967.

Hinnners, N. W., 1967. Extended LM Lunar Surface Mission Description - Case 232. Bellcomm, Inc., September 28, 1967.

Hinnners, N. W., James, D. B. and Schmidt, F. N., 1968. *A lunar exploration program.* Bellcomm Tech. Memo. 68-1012-1, 5 January 1968.

Lockheed Missiles and Space Company, 1967a. Study of Mission Modes and System Analysis for Lunar Exploration. MIMOSA Technical Report, Volume 2 - Candidate Lunar Exploration Programs. LMSC-A847942, 30 April 1967.

Lockheed Missiles and Space Company, 1967b. Study of Mission Modes and System Analysis for Lunar Exploration. MIMOSA Technical Report, Volume 3 - Recommended Lunar Exploration Plan. LMSC-A847942, 30 April 1967.

Milwitzky, B., 1967. *Automated lander missions.* NASA HQ report SL67-15702, 23 January 1967.

Vaughan, O. H., 1967. *A proposed hypothetical exploration mission in the Flamsteed Crater region of the Moon.* NASA Tech. Memo. X-53655, 14 September 1967.



5 February 1967: Lunar Orbiter 3

Lunar Orbiter 3 was intended primarily to confirm safe landing sites for the Surveyor and Apollo missions, and to provide more data on radiation intensity, micrometeoroid impacts and the shape and gravity of the Moon. The spacecraft was launched into a parking orbit at 01:17 UT from Cape Canaveral on an Atlas-Agena booster. It was placed on a lunar trajectory soon after launch and entered an elliptical lunar orbit at 21:54 UT on 8 February. To enable passes over both Apollo mission 1 and 2 primary sites with suitable lighting conditions, the orbit inclination was increased to 20.9°. The orbital altitude was 210 by 1802 km with a period of 205 minutes. After four days and 25 orbits of tracking the orbit was changed to 55 by 1847 km.

Imaging was carried out as planned except for small changes in some site locations, an additional pass over the Surveyor 1 landing site, and the dropping of the final supplementary site. The spacecraft took images over 54 orbits from 15 to 23 February, and transmitted them back to Earth until March 4, 1967 when the film advance motor burned out, leaving about 25% of the unread film stuck on the reel. In all, 211 medium and high resolution image pairs were taken, of which 157 medium and 172 high resolution frames were returned. These high quality images had resolutions as good as 1 meter. Images of the Surveyor 1 landing site showed the spacecraft and its shadow on the surface. An oblique image of the Luna 9 landing site was taken and scrutinized in the hope of seeing the lander, but its small size and unknown location made it impossible to identify.

The spacecraft was tracked for engineering and gravity studies until the end of its mission. Tracking of the Lunar Orbiters had revealed unexpected departures from the expected gravitational field (gravity anomalies) caused by uneven distribution of mass in the lunar crust. These mass concentrations (mascons) continually modified spacecraft orbits and would have to be understood for Apollo to navigate precisely. Lunar Orbiter 3 was commanded to crash near the western limb north of the Orientale basin, on 9 October 1967 at 15.7° N, 88.40° W, a point just visible on the nearside (Boeing Co., 1968). However, the spacecraft's final orbits descended 10 km lower than expected because of the effects of mascons, so impact occurred early, just past the limb on the far side. The impact site was estimated to be at 14.32° N, 92.70° W (Boeing Co., 1968) or at 14.3° N, 97.7° W (Hansen, 1970). These locations, shown in Figure 71B, are about 600 km north of the edge of the Orientale basin. The Boeing site is only 80 km from the location of the LADEE impact on 18 April 2014.

Nearside photographic coverage is shown in Figure 70. Prime sites are outlined in black, supplementary sites in grey. The prime sites are numbered to correspond with the Apollo Site Selection Board nomenclature. All prime sites were potential Apollo landing sites. The number of oblique views was increased, providing a different perspective for geological studies and offering an astronaut's perspective on some sites to assist in training and target recognition. Some images were taken to replace the lost Lunar Orbiter 1 high resolution coverage.

Farside photographic coverage is shown in Figure 71A. Figure 71B shows the two suggested impact sites. Figure 72A is a composite showing all farside imaging coverage up to and including Lunar Orbiter 3, and Figure 72B is a representative Lunar Orbiter 3 image, an oblique view of a candidate Apollo site also seen in Figure 61D.

Boeing Co., 1968. *Lunar Orbiter III: extended mission spacecraft operations and subsystem performance*.

NASA Contractor Report CR 1109, Boeing report D2-100753-4. Seattle, Washington: Boeing Co.

Hansen, T. P., 1970. *Guide to Lunar Orbiter Photographs*. NASA SP-242. Washington, D. C., National Aeronautics and Space Administration.



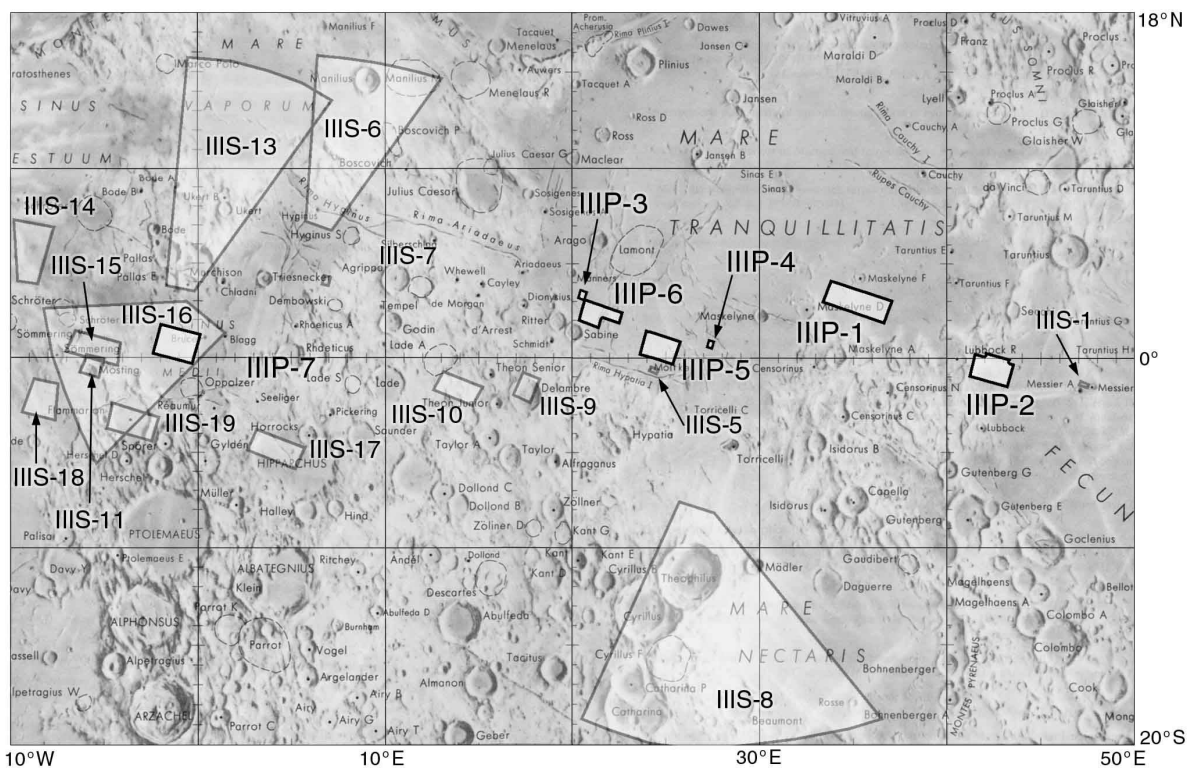
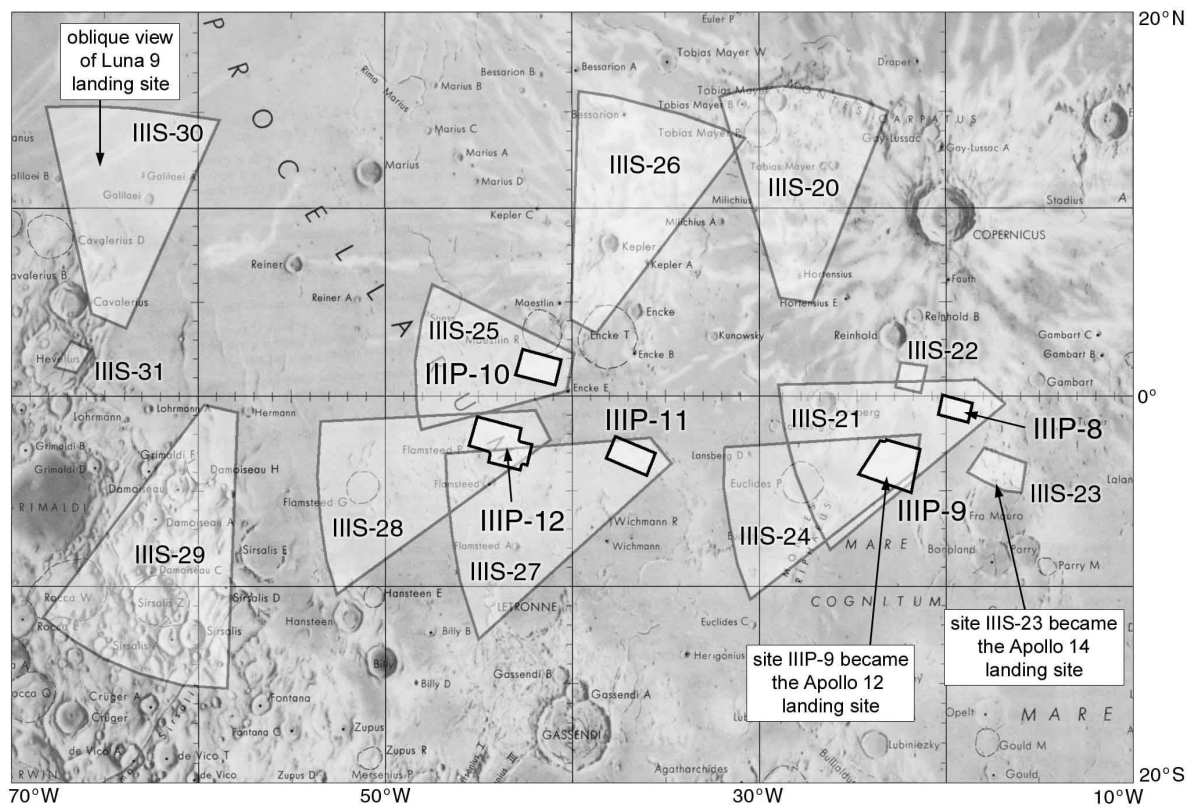


Figure 70. Lunar Orbiter 3 nearside image coverage.

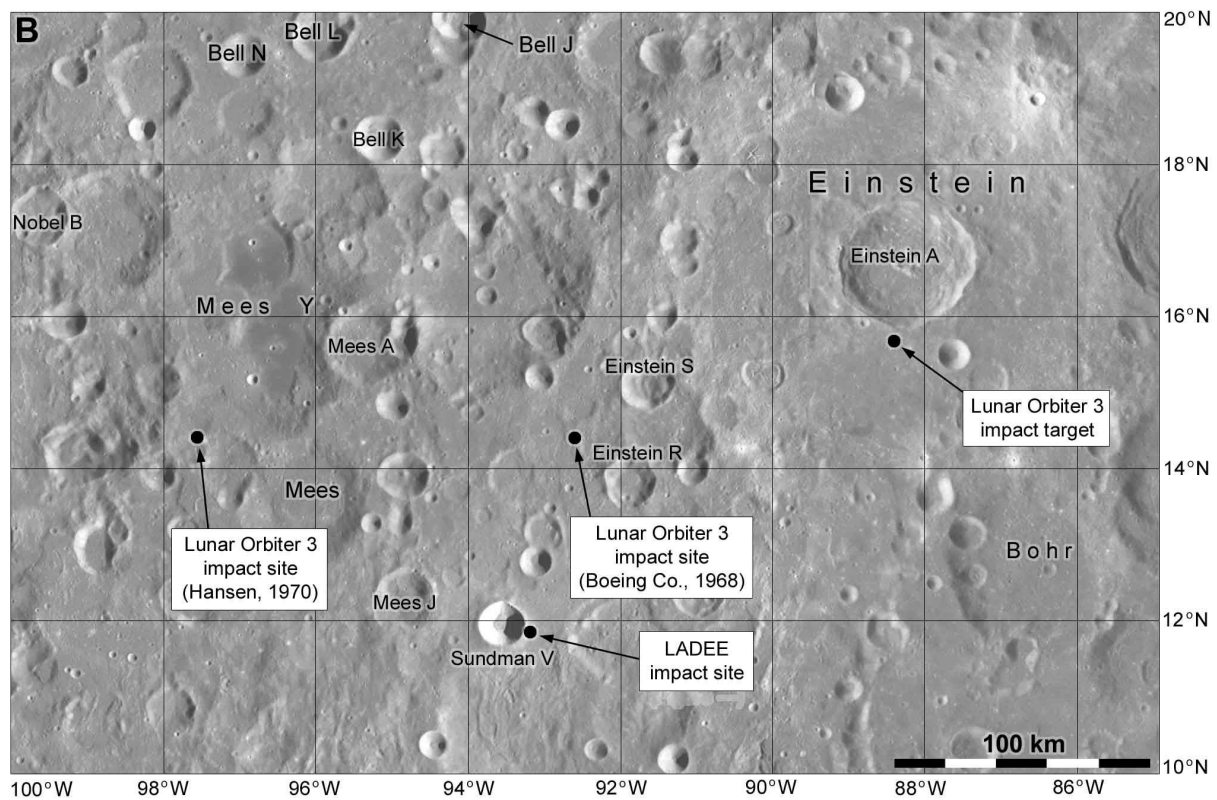
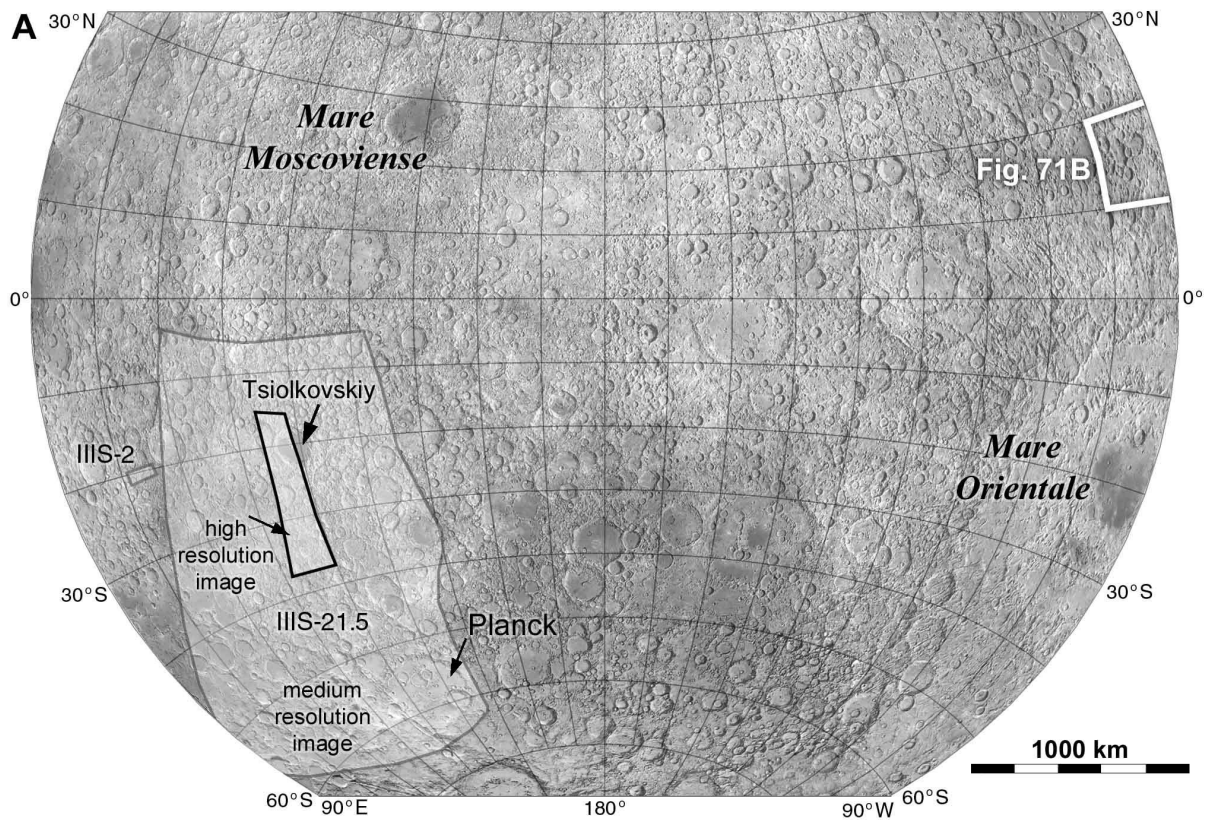


Figure 71. Lunar Orbiter 3 farside image coverage and impact site. A: Farside imaging. B: Impact target and two possible impact sites, also showing the location of the LADEE impact in 2014.

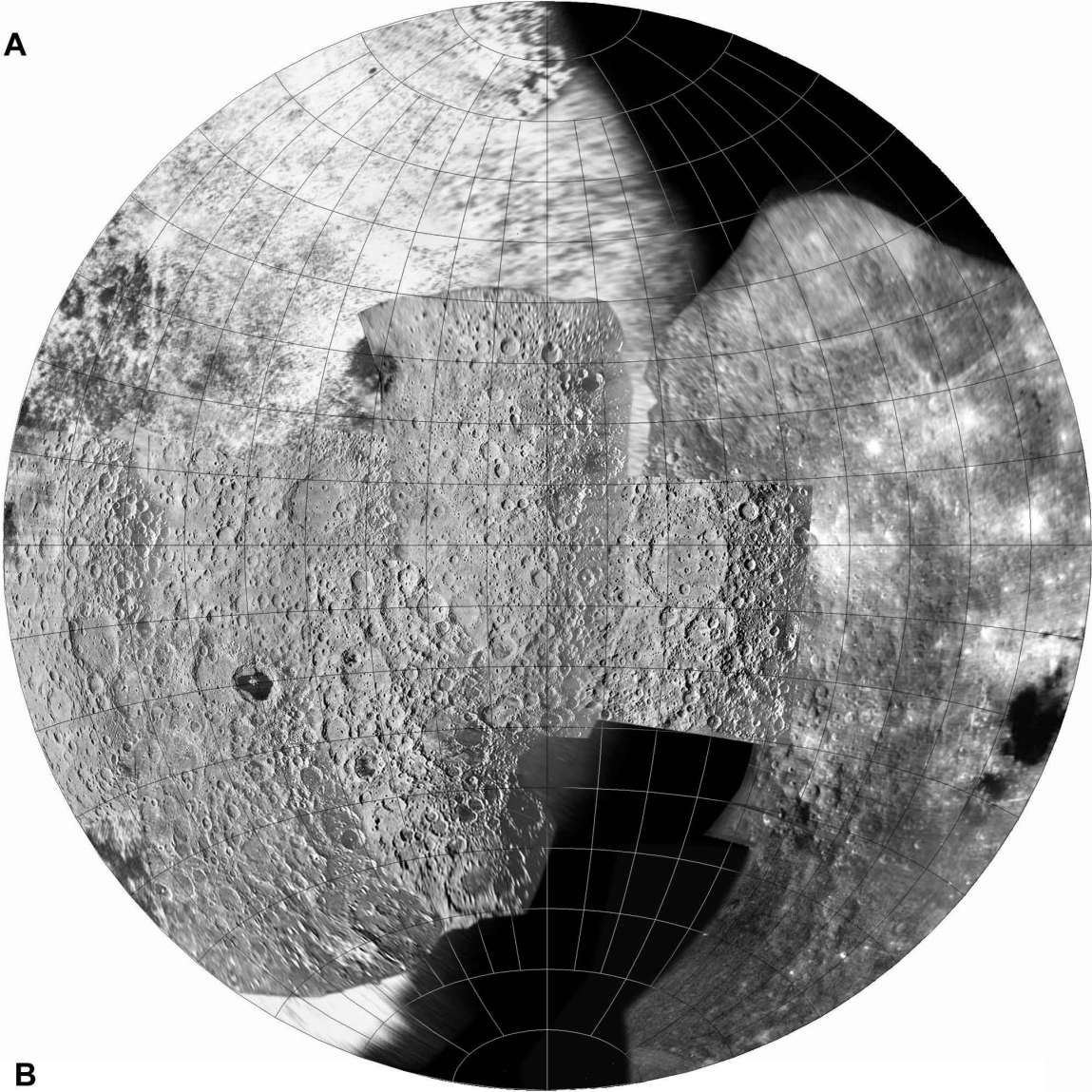
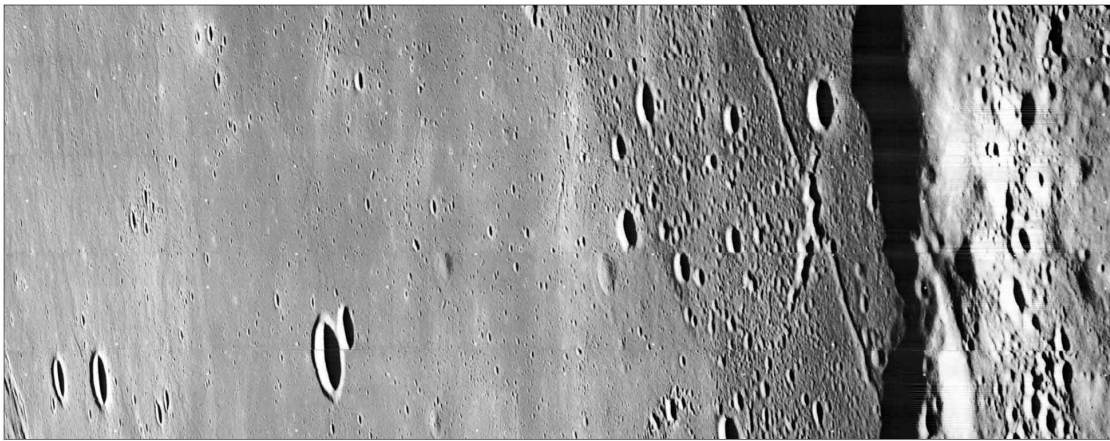
A**B**

Figure 72. Lunar Orbiter 3 images. A: Farside image coverage after Lunar Orbiter 3. This map follows Figure 58A and the sequence continues in Figure 82A. B: a sample of Lunar Orbiter 3 photography. This oblique view looks west across the potential Apollo landing site IIIP-10. Lunar Orbiter 3 image III-161-M.

1967: Lunar Orbiter 3 Site Screening

The Lunar Orbiter 3 photography extended Orbiter 2 coverage and recovered some Orbiter 1 data lost to the image smear problem. Eight of the thirteen prime sites were screened in detail for landing sites (Figure 73). As in Figures 53 and 59 the candidate landing sites are shown as ellipses, with sites preferred after screening shown in black. All ellipses are 7.9 by 5.3 km, indicating the scale of the images. Figure 70 shows the location and orientation of each site.

Where the Orbiter 3 prime sites overlapped Orbiters 1 and 2 sites, some ellipses were common to the previous screening results (e.g. III-1-1 and II-2-1) and are indicated by dual labels. Some Orbiter 1 ellipses are labelled ‘A’ and some ‘I’, a discrepancy that follows the source materials (Lunar Orbiter Photo Data Screening Group, 1967).

Lunar Orbiter Photo Data Screening Group, 1967. *Preliminary geologic evaluation and Apollo landing analysis of areas photographed by Lunar Orbiter III*, Langley Working Paper LWP-407, June 1967.



30 March 1967: Apollo Site Selection Board

ASSB met on 30 March 1967 to evaluate landing sites. The Lunar and Earth Sciences Division at MSC had evaluated the Lunar Orbiter 2 images and screening results (Figure 59) and presented a shortlist of six candidate landing sites at this meeting. Of the thirteen Orbiter 2 imaging sites, sites IIP-5 and IIP-6 in Mare Tranquillitatis were both suitable, but were so close together that site 5 was dropped, leaving five sites on the shortlist.

Table 25. Orbiter 2 screening results, ASSB meeting, 30 March 1967

sector	rank (* suitable)	site number	location	thermal anomalies	surveyor site
East	1*	IIP-6	0° 45' N, 23° 37' E	cool area	no
	2*	IIP-2	2° 40' N, 34° 00' E	cool area	no
	3*	IIP-5	2° 40' N, 24° 25' E		
	4	IIP-3	4° 12' N, 21° 03' E		
	5	IIP-1	4° 00' N, 38° 45' E		
Central	1*	IIP-8	0° 25' N, 1° 20' W	none	yes
	2	IIP-9	0° 55' N, 12° 55' W		
	3	IIP-7	1° 53' N, 1° 52' W		
	4	IIP-4	(rejected)		
West	1*	IIP-11	0° 25' N, 19° 55' W	warm area	yes
	2*	IIP-13	1° 40' N, 41° 40' W	between two cool areas	no
	3	IIP-12	1° 42' N, 34° 12' W		
	4	IIP-10	3° 18' N, 27° 12' W		
other sites considered at this time					
Central		IP-5-1	0° 48' N, 2° 30' W	cool area	yes
West		IP-7-1	3° 00' S, 23° 12' W	none	yes
		IP-7-3	3° 12' S, 23° 06' W	none	yes
		IP-9.2b-1	2° 12' S, 44° 30' W	none	yes
		Surveyor 1	2.15° S, 43.35° W	none	landed

The best Orbiter 3 sites (not yet available for this meeting) would be added to this shortlist later in the year to create the Set B candidate sites for the first Apollo landing. Orbiter 1 sites were not included because of the lack of useful high resolution frames from that mission.

Figure 73B shows the Orbiter 2 primary sites and identifies those considered most suitable. Table 25 lists the coordinates and characteristics of all sites considered at this meeting. The inconsistent use of decimal degrees or degrees and minutes reflects inconsistencies in the original documents. Thermal anomalies were measured during lunar eclipses and indicate areas which change temperature more or less rapidly than average during an eclipse. Rocky sites, which would be expected to remain warmer than average during an eclipse, might be too rough for a landing.



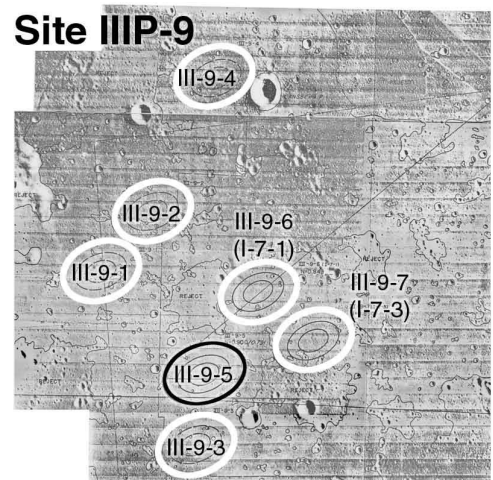
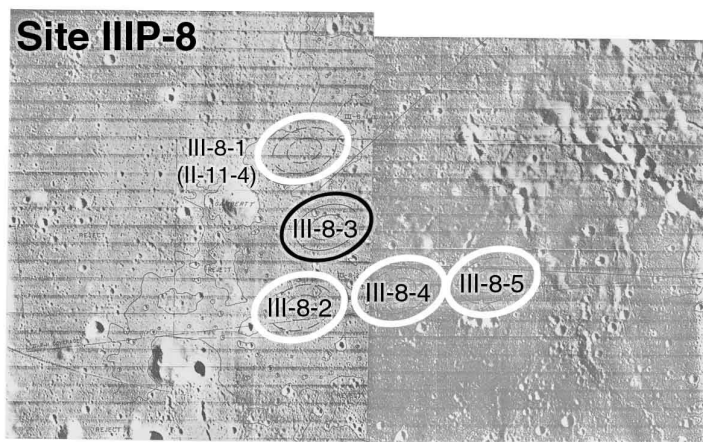
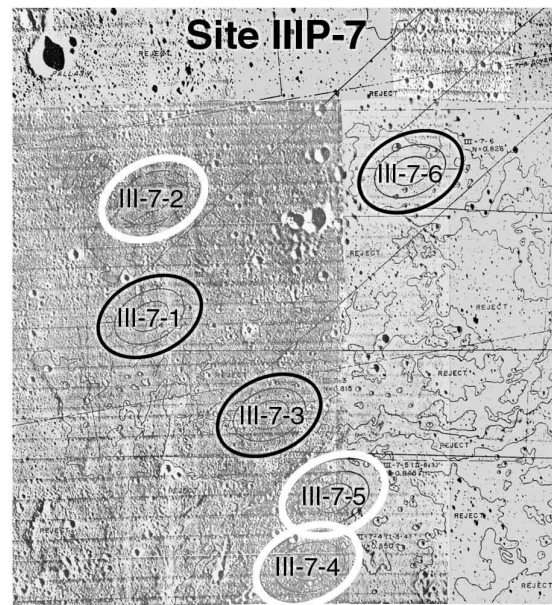
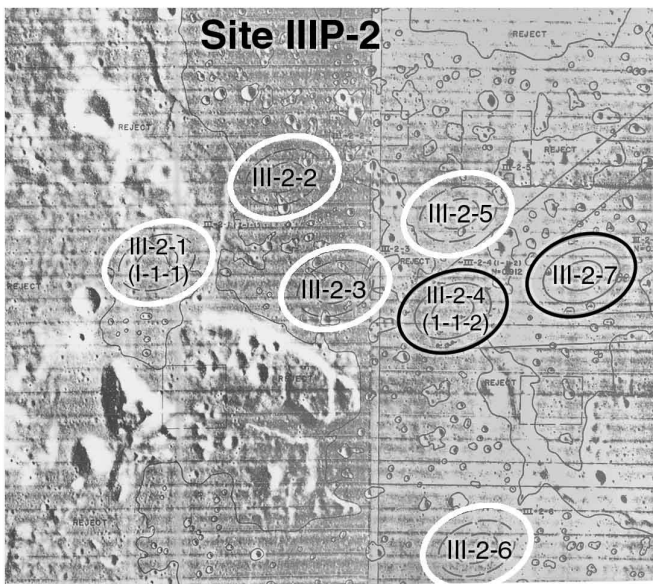
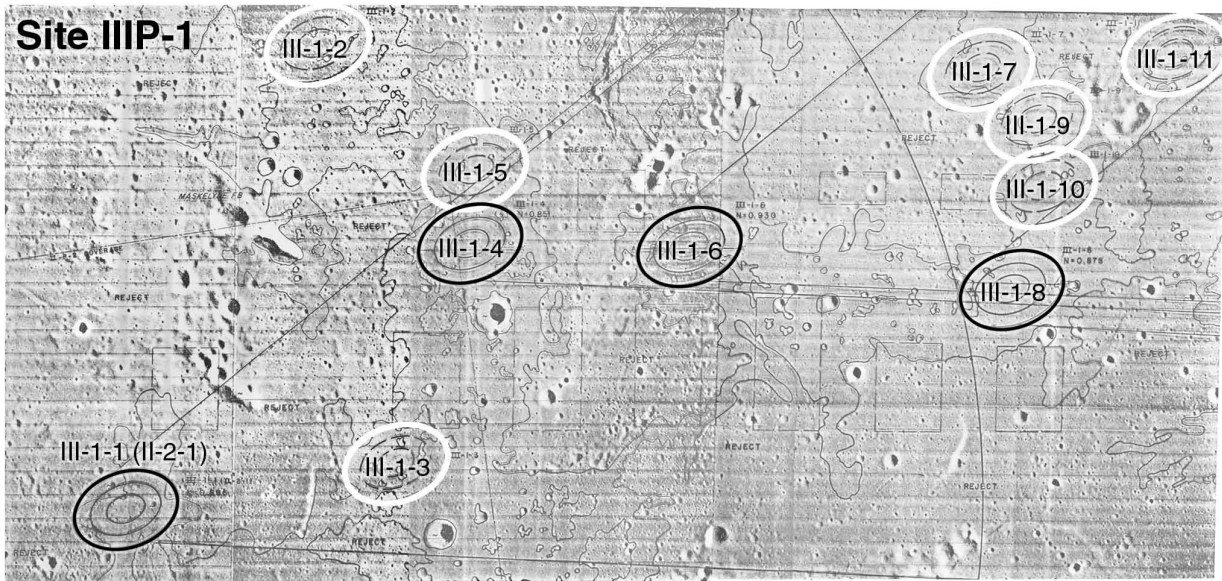
1967: Space Accidents

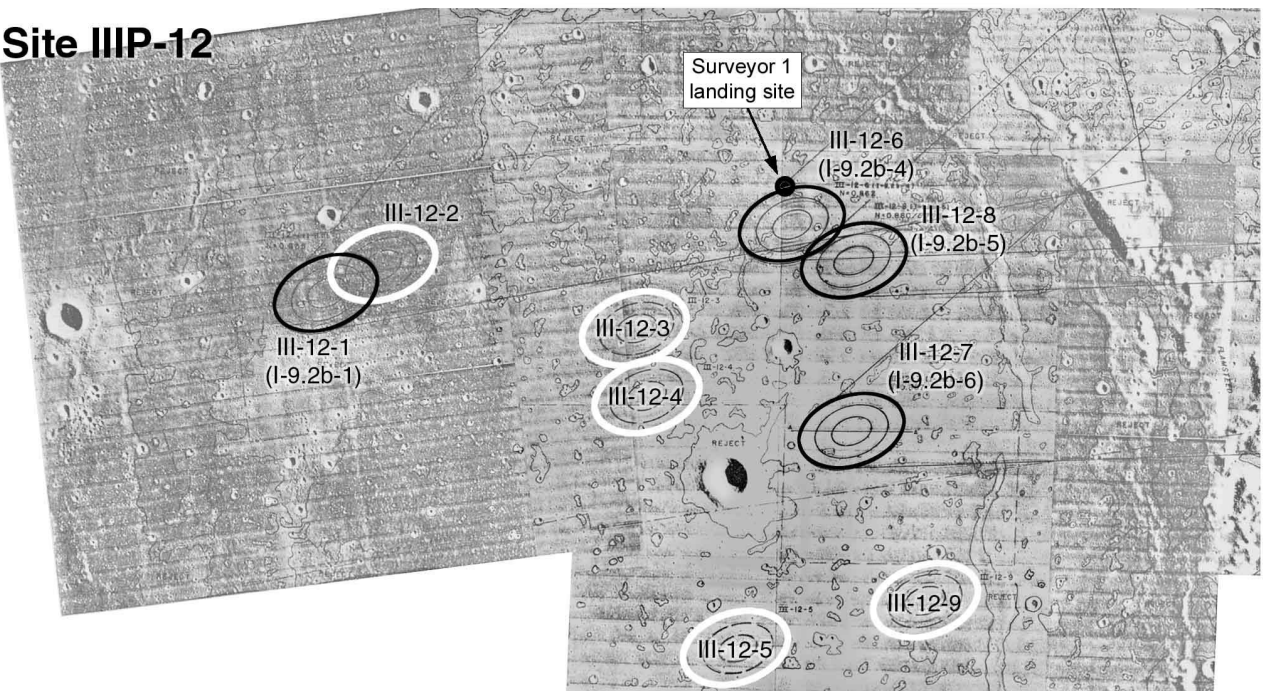
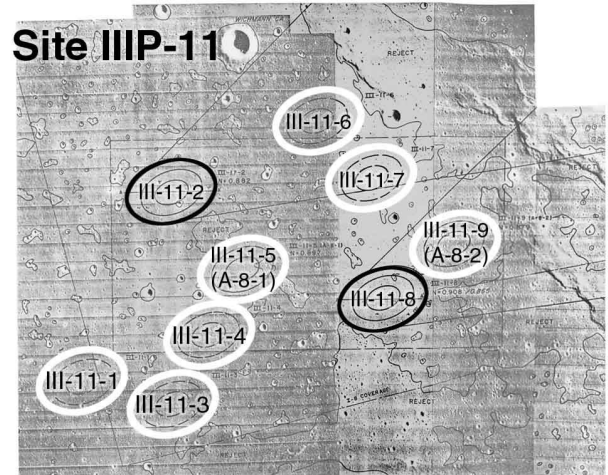
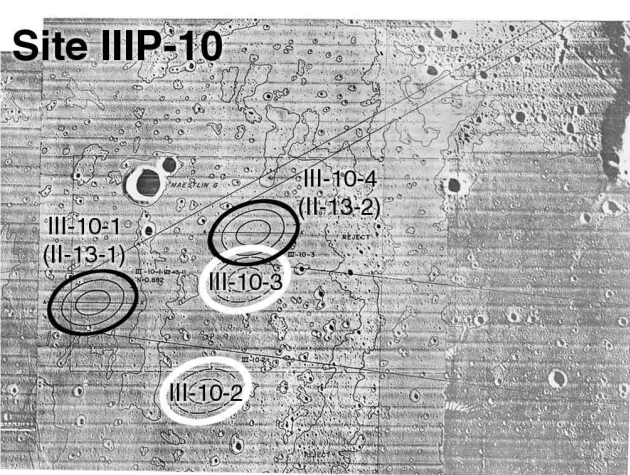
Lunar craters are named for people associated with the Moon or astronomy, and names are not usually assigned until at least three years after the person's death. In the era of space exploration some craters have been named after astronauts and cosmonauts, and in a few cases their names have been assigned during their lifetimes. 1967 saw the first space fatalities (the fate of Valentin Bondarenko was not known at this time and will be covered later). The Soviet Union lost a cosmonaut during a flight, and the United States lost three people during a ground test in a three month period.

Soyuz ('Union'), the new Soviet spacecraft, replaced the Vostok and Voskhod capsules used by the earliest Soviet cosmonauts, and was designed to take crews to the Moon. Soyuz 1, the first piloted test flight, was launched on 23 April 1967. Technical problems necessitated a return to Earth after only 18 orbits and about 27 hours. Vladimir M. Komarov died when the main parachute failed to deploy and the reserve parachute became tangled. His ashes were buried in the Kremlin wall and a crater near Mare Moscoviense was named after him in 1970 (Figure 74A). Nearby craters commemorate other early cosmonauts, including Valentina Tereshkova, the first woman in space, and Alexei Leonov, the first person to 'walk' in space outside a spacecraft. The first cosmonaut, and first human in space, Yuri Alekseyevich Gagarin, was recognized separately by attaching his name to a large impact basin between Mare Moscoviense and Tsiolkovskiy. Gagarin had flown in the Vostok 1 capsule on 12 April 1961 and died in an aircraft crash on 27 March 1968 at the age of 43.

Three months before Komarov's death a spacecraft countdown test at the Kennedy Space Center had failed catastrophically on 21 January 1967. The Apollo 1 command module, originally designated Apollo 204, sat on its unfueled Saturn 5 at the launch pad. If all had gone well it would have been launched with its crew on 21 February for an Earth-orbital test flight. At 23:31 UT a fire started in a bundle of wiring with worn insulation and spread rapidly in the capsule's pure oxygen atmosphere. The crew, Edward White (first American to walk in space), Virgil 'Gus' Grissom (one of the seven original Mercury astronauts) and Roger Chaffee, died before the awkward hatch could be opened. The fire delayed the first lunar landing for over a year as the spacecraft was redesigned and work procedures were improved. In 1970 the International Astronomical Union assigned the names of the astronauts to craters near a large farside impact basin which received the name Apollo (Figure 74B).







ASSB screening results

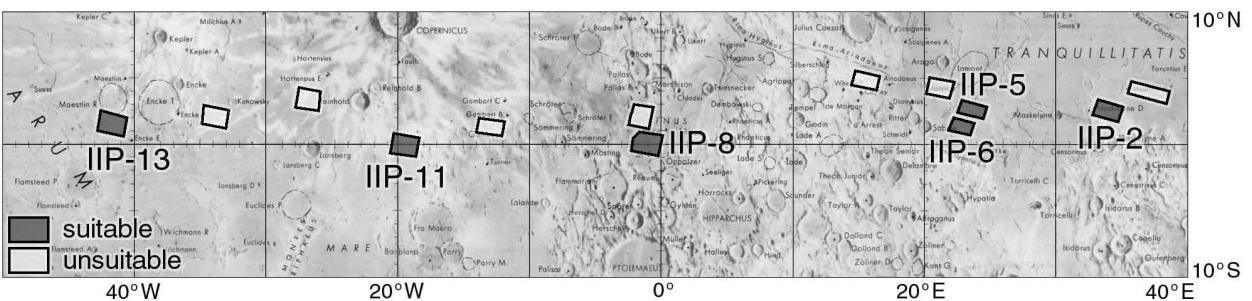


Figure 73 (both pages). A: Lunar Orbiter 3 site screening results. B: the results of Apollo site screening from the 30 March 1967 ASSB meeting, still using only Lunar Orbiter 2 sites. The base map is ACIC Lunar Earthside Chart (LMP-1), original scale 1:5 million; first edition January 1970.

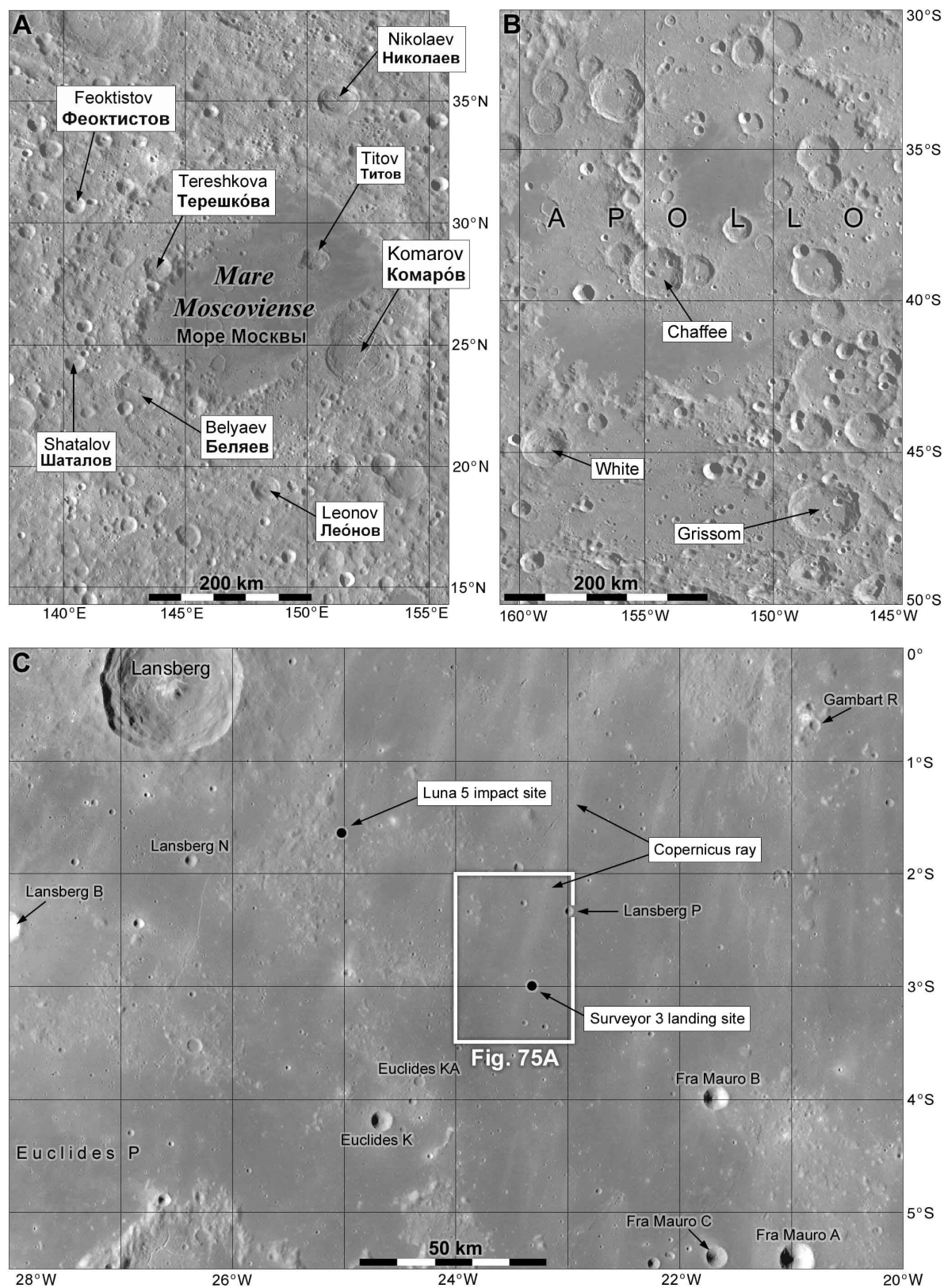


Figure 74. Space flight commemorative craters and Surveyor 3 location. A: craters commemorating Soviet cosmonauts. B: craters commemorating the Apollo 1 crew. C: The Surveyor 3 landing region.

17 April 1967: Surveyor 3

Surveyor 3 was identical to Surveyors 1 and 2 except that the unused descent imaging camera was removed and a sampling arm was added. This could be controlled from Earth to dig trenches and obtain surface properties data. Two mirrors were mounted on the spacecraft frame to provide views underneath the spacecraft.

The spacecraft was launched at 07:05 UT from Pad 36B at Cape Kennedy (JPL, 1967b; NASA 1967a). Following a midcourse correction 22 hours after launch the spacecraft landed close to its target at 04:53 UT on 20 April. Telemetry from Surveyor 3 showed that it touched down on the lunar surface and lifted off again twice before coming to rest because the vernier (final descent) engines did not shut down as expected at the moment of landing. The spacecraft hopped westwards (downhill) between 15 and 22 m between the first and second surface contact and from 11 to 14 m between the second and third contacts. The verniers were shut down by command from Earth just before the third touchdown. Because it landed on the sloping wall of a crater, it also slid about 30 cm downhill following the final landing. The footpad imprints in Figures 77B, 78E and 79B show the last motion before the spacecraft came to rest. Three small (2 cm) rock fragments were apparently blown across the surface by vernier engine exhaust (Figures 78A, 78B, 80A).

The landing site was at 3.016° S, 23.418° W in LRO coordinates (Wagner *et al.*, 2017), which was given as 2.94° S, 23.33° W at the time, in eastern Oceanus Procellarum, in a region where many small hills protrude above the lava plains. The area was later named Mare Insularum (Sea of Islands). The original target was at 3.33° S, 23.17° W, with a 99 percent chance of landing within 30 km of that point. If no midcourse correction or braking had been attempted, impact would have occurred at 10.07° S, 36.99° W. Only a small correction was needed, and the accurate trajectory allowed a smaller landing ellipse to be defined, 15 by 10 km with a revised target point at 2.92° S, 23.25° W to avoid two craters to the south. Tracking suggested a landing at 3.00° S, 23.43° W. The actual landing point was eventually located by Ewen Whitaker of the University of Arizona by comparing features seen in the first Surveyor 3 images with Lunar Orbiter 3 views of the area. The target and landing points are illustrated in Figure 75.

Figure 75D also indicates the Surveyor 3 retro-rocket impact location, identified by Stooke (2010). A small dark spot 250 m north of the lander is visible in high sun LRO images (Figure 76A). It was not present in the pre-landing Lunar Orbiter image of the site (Figure 76B), and is clearly resolved as a 5 m diameter crater in the best LRO images (Figure 76C). High sun images (Stooke, 2016) show two small dark spots south of the new crater, initially interpreted as bounce marks made by the rocket during its impact, but seen to cast a shadow in Figure 76C and an Apollo 12 descent image, and now interpreted as the retro-rocket nozzle or another fragment of the rocket, ejected during the impact.

Surveyor 3 landed inside a shallow 200 m diameter crater. Two block fields on the rims of small fresh craters shown in Figure 76D were visible in Surveyor 3 panoramas (Figure 78). Apollo 12 landed within the area of Figure 76D on 19 November 1969. The Army Map Service documented the landing with maps of the site which show the nature of the landing area.

Figure 77 presents detailed plans of the Surveyor 3 landing site derived from Figures 3.8 and 3.9 in NASA (1967). The locations of the three touchdowns during landing are shown in Figure 77A. Surveyor 3 came to rest straddling a shallow 2.5 m diameter crater on the eastern inner slope of the 200 m diameter crater. The relief drawing shows a characteristic ‘treebark’ texture found on many lunar hillsides and crater walls, thought to be produced by downslope movement of regolith caused by impact-induced shaking.

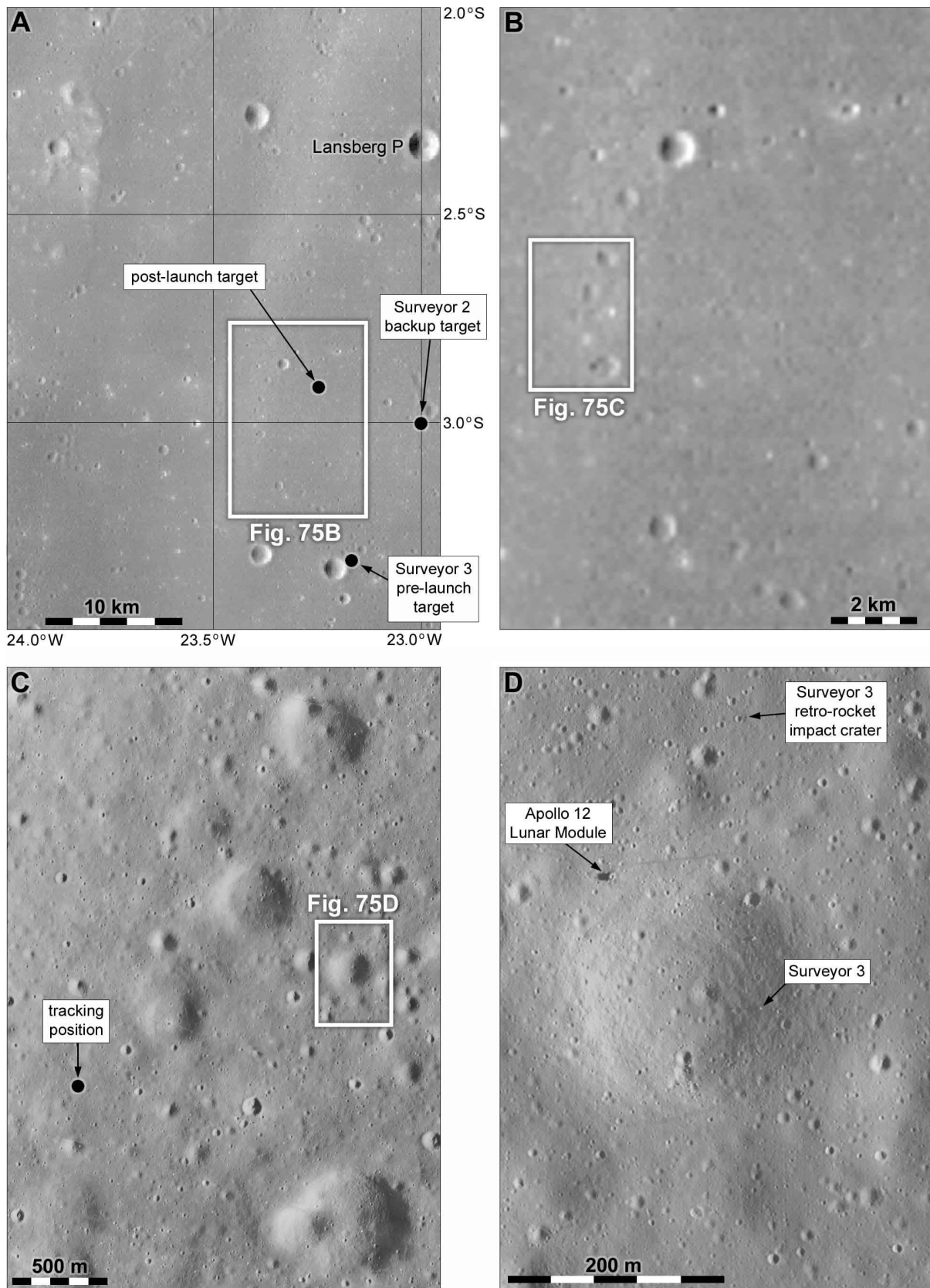


Figure 75: Surveyor 3 landing site. C is Lunar Orbiter 3 image III-137-H2. D is LROC image M177785917L.

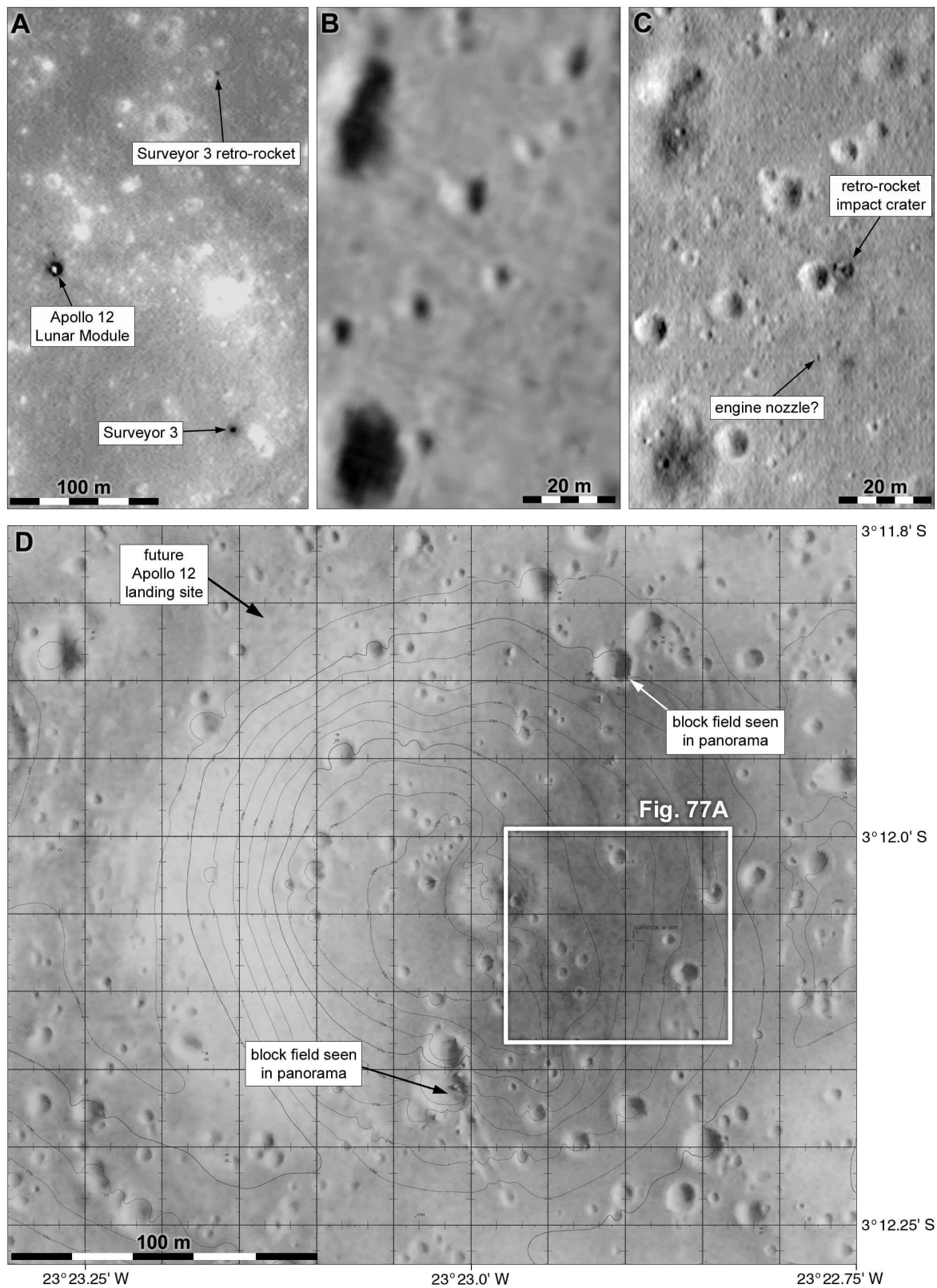


Figure 76. Surveyor 3 retro-rocket location and landing site map. A: high sun LROC image M107035386R. B: pre-landing Lunar Orbiter 3 image III-154-H2. C: LROC image M175428601R, showing the retro-rocket impact crater. D: Army Map Service Lunar Map, Surveyor III Site, original scale 1:500, 1st edition February 1968.

Surveyor 3 landed with its vernier engines still firing. Dust thrown up by the verniers either coated parts of the camera mirror or pitted and eroded the mirror in places, causing some loss of quality in the images. Dust may also have clogged the mirror pointing mechanism, limiting its motion range. These effects reduced the number, coverage and quality of images. One nearly complete panorama can be assembled to show the interior of the crater in which the spacecraft landed (Figure 78A).

The full panorama spans about 80 per cent of the horizon, missing the sector between west and northwest. This image was created by scanning assembled panorama segments preserved at the Lunar and Planetary Laboratory, University of Arizona, and removing numerous visual defects. Trenches 1 (right) and 2 (left, see Figure 80A) are visible at the bottom of the panorama and enlarged in Figure 78B. The tracks labelled in Figures 78A, 78B and 80A were made by small rocks set in motion by the vernier exhaust during landing.

The Surveyor 3 panorama shown here appears bland partly because image contrast was reduced by dust on the camera mirror, but also because the sun was high in the lunar sky during most of these photographic sessions. The block field in Figures 78C and 78D surrounds a pair of craters south of the spacecraft, identified in Figure 76D. Figure 78E shows the footpad imprints (labelled 'F') made during the second touchdown, as shown in Figure 77A. The photometric target shown in Figure 78A was one of two, the second mounted on the omnidirectional antenna at far left. All Surveyors carried these targets to permit colour image reconstruction. Colour images could be obtained by taking images through three filters, but only a few small scenes were imaged in colour by the Surveyor spacecraft.

Figure 79A is an enlarged section of the full panorama looking northwards towards several prominent rocks and small craters. Features in this area were used by Ewen Whitaker (Lunar and Planetary Laboratory, University of Arizona) to locate the spacecraft in Lunar Orbiter images. Surveyor 3 transmitted several wide-angle images of this area lit by a very low sun immediately after landing. The height of the horizon suggested that the landing site was inside a crater a few hundred meters in diameter. The double rock at upper center, a crater just below it and a rock-rimmed crater nearer the horizon were thought likely to be visible in Orbiter images.

Whitaker examined numerous craters in the vicinity of the expected landing point and eventually found a set of features which matched those seen in the surface pictures. Additional matching features were quickly found to confirm the location. This method of matching surface and orbital images has been used to locate landed spacecraft on the Moon and Mars ever since. Whitaker's discovery of the exact landing location prompted the selection of the Surveyor 3 site as the target for Apollo 12, and after the Lunar Module landed on the crater rim to the left of Figure 79A the astronauts saw Surveyor 3 sitting in its crater as predicted.

A single image (Figure 78C) and a detail from the Surveyor 3 panorama (Figure 76D) show part of the block field south of the lander, also indicated on Figure 76D. The regularly spaced dots (reseau marks) on Figure 78C were common on all NASA spacecraft images until the 1980s. They were intended to help correct distortions in photographic prints of the images. A diffuse dark patch near the horizon is an artifact caused by dust on the camera mirror.

The Surveyor 3 robotic arm (surface sampler) was the first active device capable of manipulating its surroundings to be landed on another world. The 'arms' of Luna 13 were passive deployment devices, incapable of movement after they had deposited their instruments on the surface. The area accessible to the surface sampler is shown in Figure 80A. A rock near the footpad at upper left is visible in the panorama (Figure 78A). Table 26 lists the daily surface sampler activities. The three images in Figure 80B show the sample arm in operation, with a footpad imprint at far left. In the two right-hand images, trench 1 is at left and the arm is digging trench 3. The surface activity map (Figure 80A) is derived from Scott and Roberson (1968) and JPL (1967).

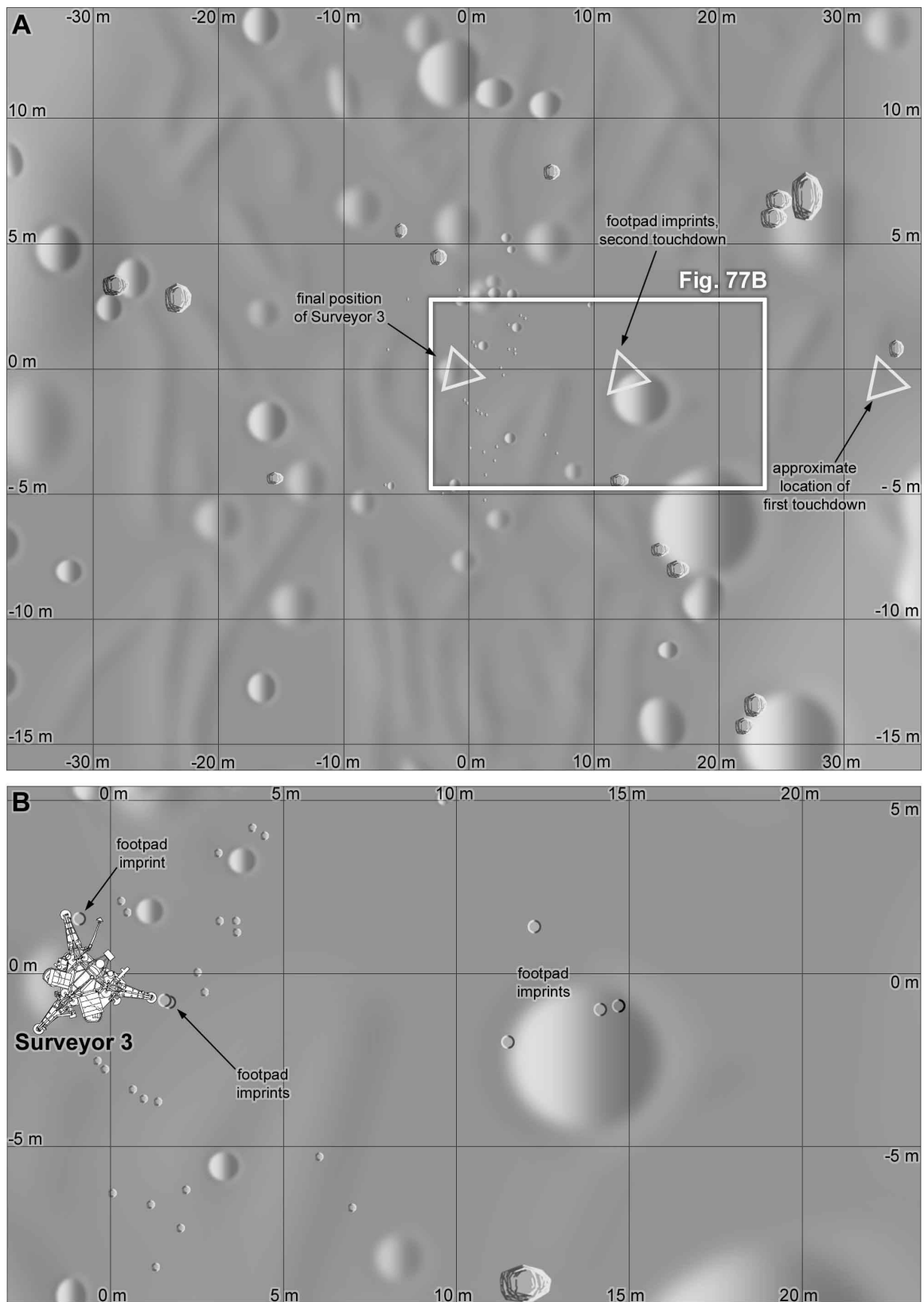
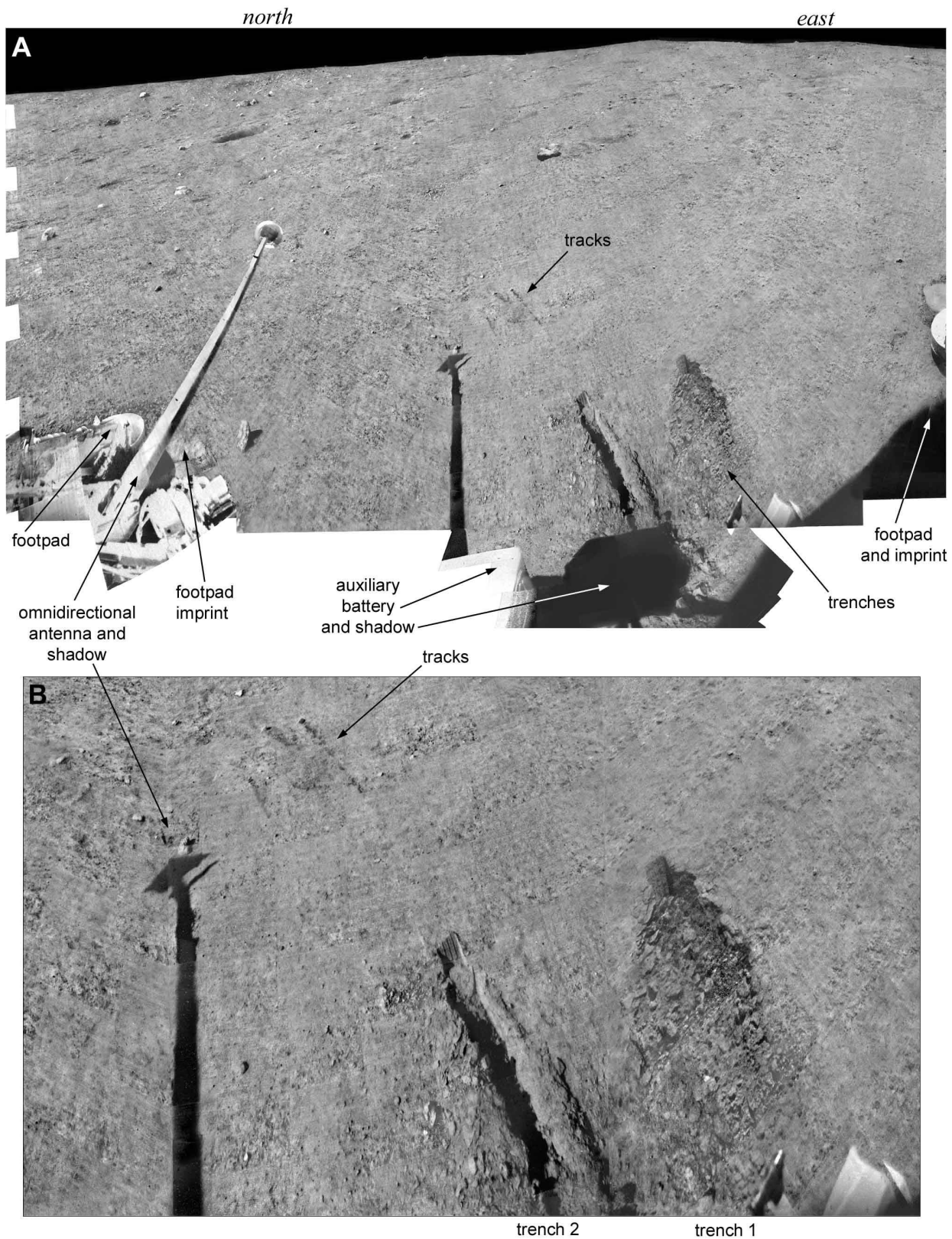


Figure 77. Plans of the Surveyor 3 site. These shaded relief drawings by P. Stooke are based on Figures 3.8 and 3.9 in NASA (1967).



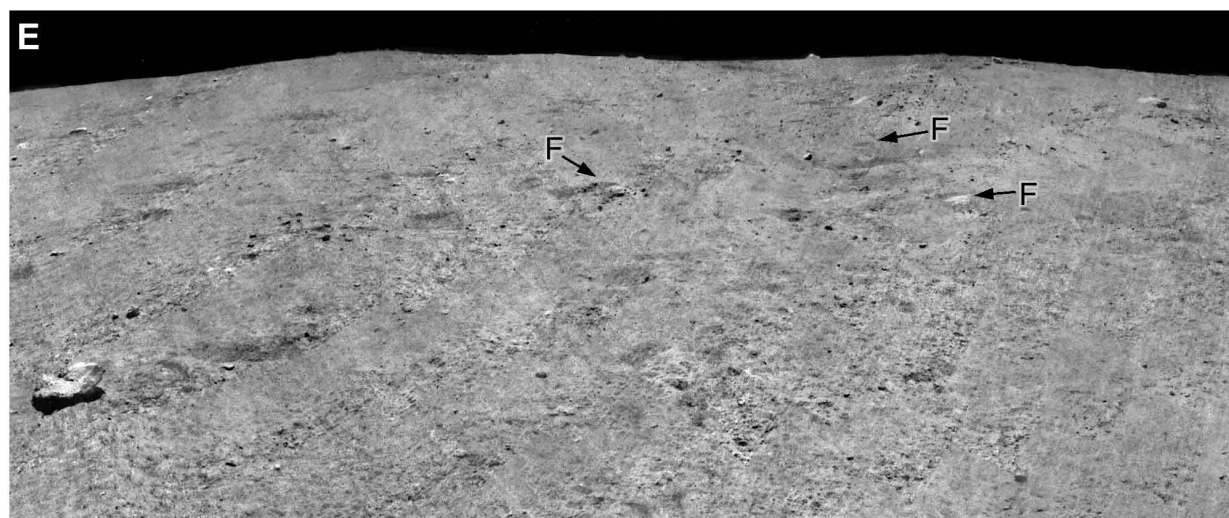
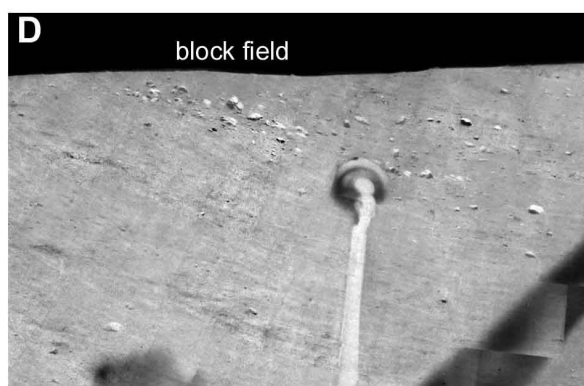
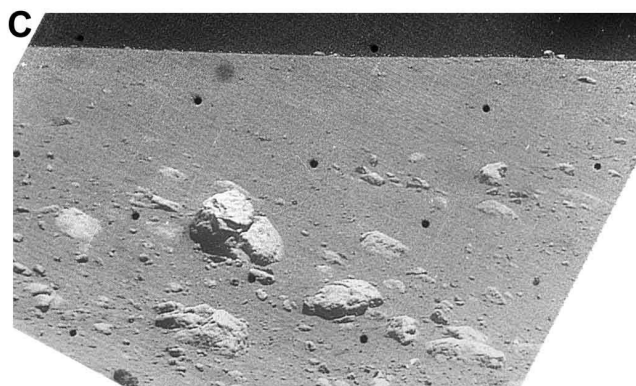
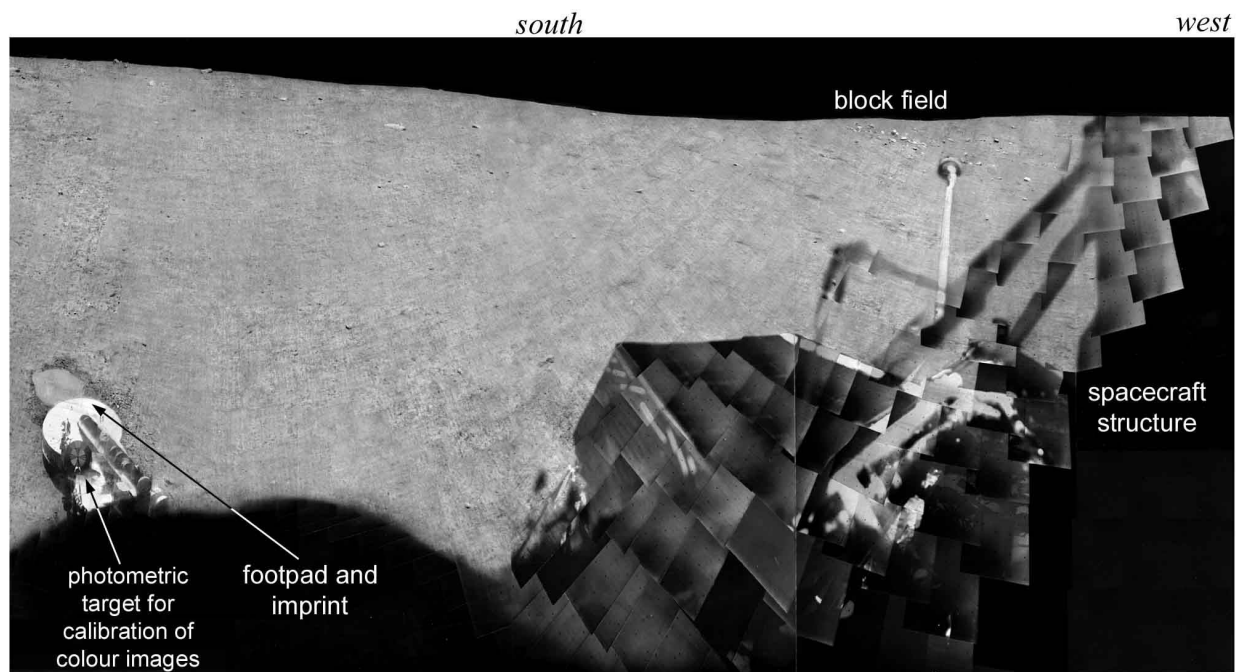


Figure 78 (both pages). Surveyor 3 panorama. A: full panorama. B: detail showing two trenches. C, D: block field south of the lander. E: footpad imprints uphill from the lander, made during the second touchdown.

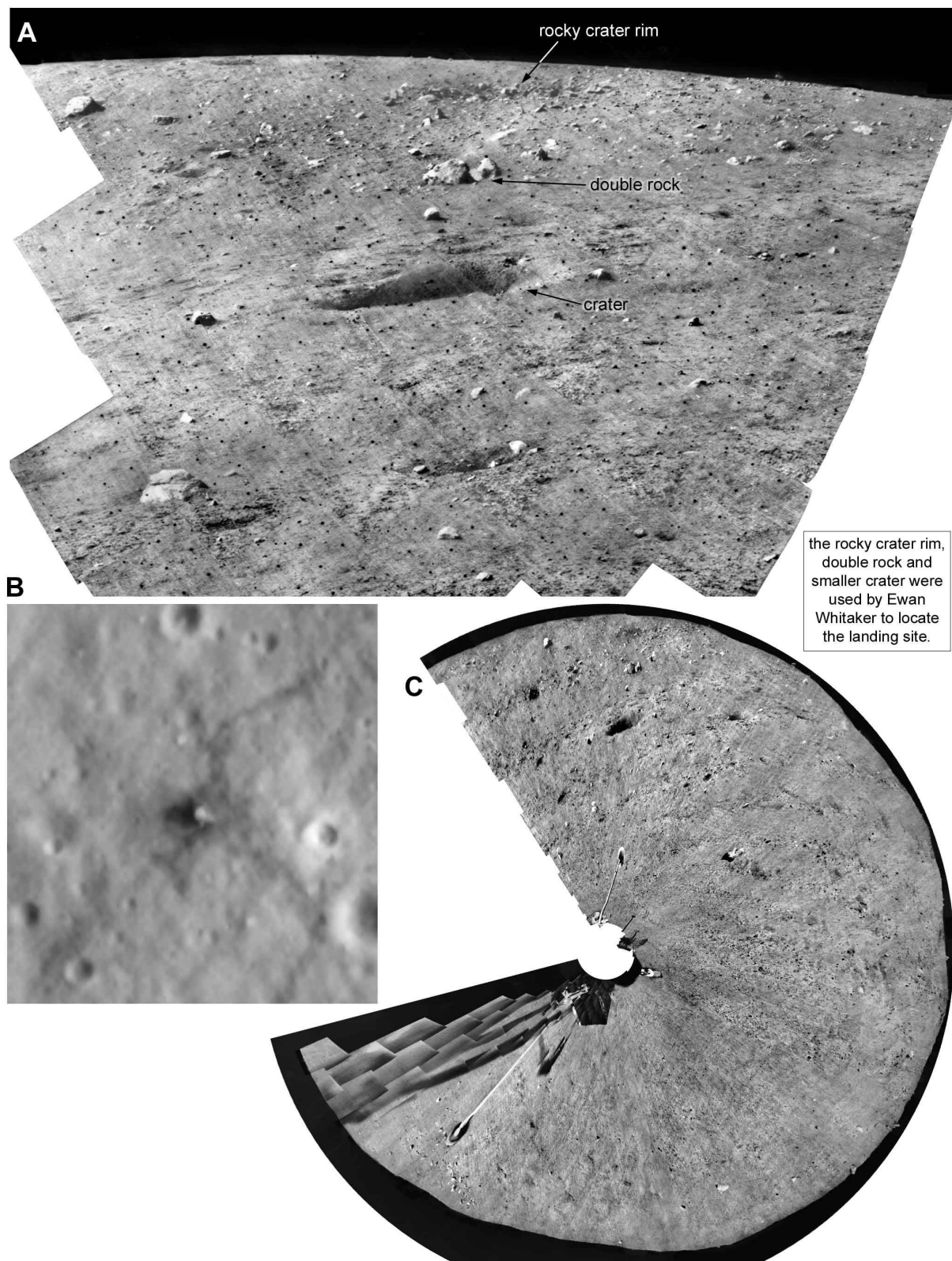


Figure 79. Surveyor 3 landing site. A: the horizon north of Surveyor 3. B: Enlarged composite of 7 LRO NAC images of Surveyor 3. C: reprojected Surveyor 3 panorama.

Table 26. Surveyor 3 sampler operations	
day	actions
21 April	Sampler released, tested, moved to a position above point b1 and left there
22	Press surface at b1, dig trench 1, dig trench 2, and sampler left in trench 2
23	Two more passes through trench 2. Sampler left at the end of trench 2
24	Solar eclipse. Too hot to operate sampler
25	Too hot to operate sampler
26	Clod of soil picked up at contact 1 (c1), moved to footpad. Scoop lowered to the surface short of the footpad, repositioned over the footpad, and soil deposited on the footpad
27	Press surface at b2 and b3, dig trench 3
28	High albedo object picked up at contact 2 (c2), placed on footpad. Two more passes through trench 3 to widen it. Press surface at b4
29	Impact tests at i1, i2, i3, i4, i5, i6. Arm motors tested
30	Press surface at b5. Sampler touches and moves an object at contact 3 (c3). Bearing tests at b6 and b7, Impact tests at i7, i8, i9, i10
1 May	Object at c3 picked up, photographed in color, dropped and not seen again. Three more passes in trench 2, four impacts in the trench before the last pass to loosen material
2	Impact tests at i11 and i12. Dig trench 4. Impact test at i13, arm left extended beyond trench 4

In Table 26 the days are dates in April and May 1967. Trenches, surface contact points (c1 to c4) and soil test sites are numbered in chronological order. Impact tests (i1 to i13) involved allowing the arm to fall from a height to indicate depth of penetration. Bearing tests (b1 to b7) involved pushing down with the arm until the motor stalled. Trenches 1 and 4 were dug with a single sweep of the arm. Trenches 2 and 3 were made with multiple passes, digging to a depth of 15 cm or more. At point c1 a small clod of soil, thought to be a rock, was picked up in the scoop, but was crushed. The soil was dropped onto the nearby footpad. At c2 soil and a small rock were picked up and dropped on the footpad. At c3 a rock was picked up and photographed through colour filters. It was dropped and not seen again.

Surveyor 3 returned 6315 images of its landing site, dug four trenches, performed 22 soil mechanics tests, and survived a lunar eclipse on April 24, taking images of Earth with the Sun behind it but backlighting its atmosphere. This observation was not repeated until the Firefly Blue Ghost Mission 1 lander saw the same phenomenon on 14 March 2025. The spacecraft was still in good condition at the end of the first lunar day, on 4 May, and just after sunset the camera took a long exposure image of the constellation Orion. Throughout the next lunar day, from 23 May to 2 June, many attempts were made to regain contact with Surveyor 3, but all were unsuccessful. Surveyor 3 was visited by the Apollo 12 astronauts on 20 November 1969, and some parts of the spacecraft including its camera and scoop were brought back to Earth.

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 Shoemaker, E. M., Batson, R. M., Holt, H. E. *et al.*, 1968. Television observations from Surveyor 3, *Journal of Geophysical Research*, v. 73, no. 12, pp. 3989–4043. doi:10.1029/JB073i012p03989
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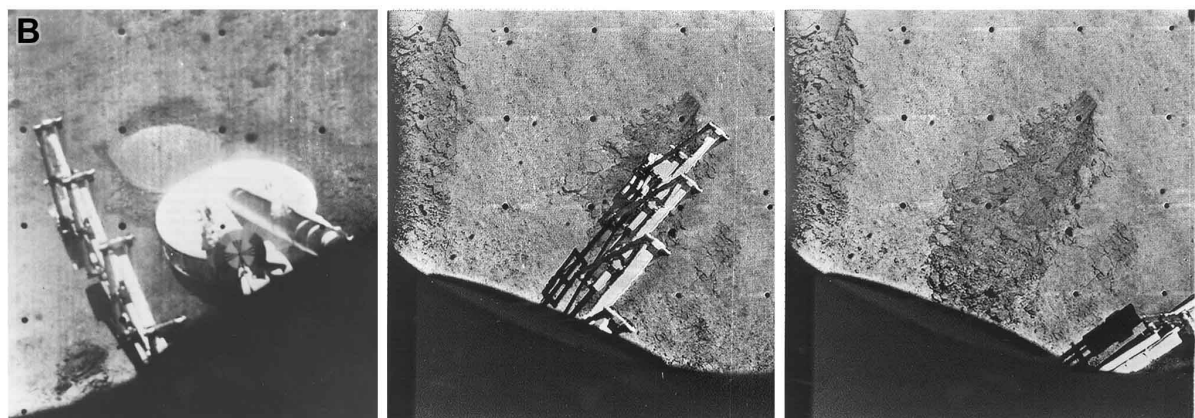
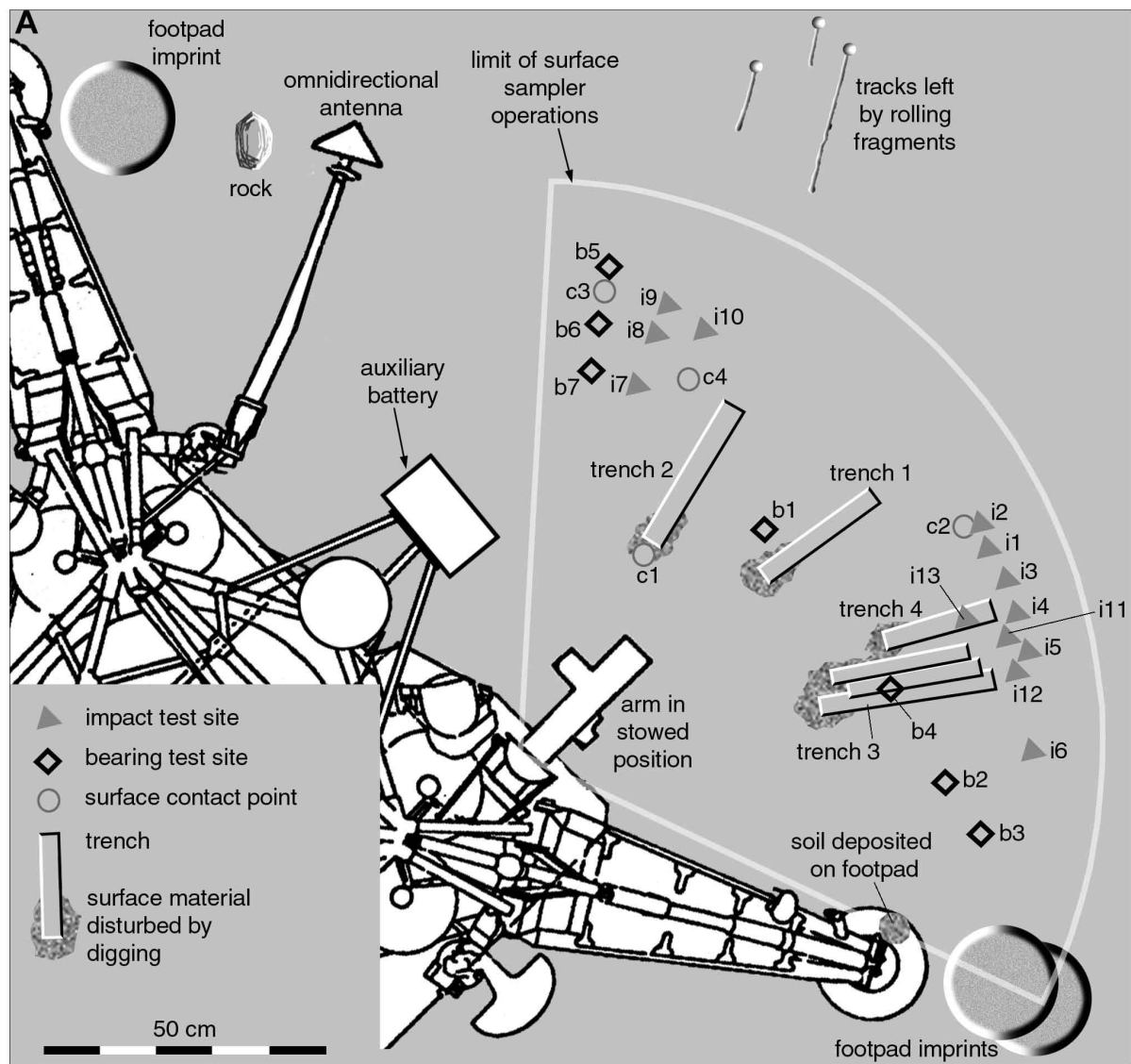


Figure 80: Surveyor 3 surface activities. A: robotic arm activities (Scott and Roberson, 1968; JPL, 1967b). B: The arm in action. Left: near a footpad and imprint. Centre and right: trench 1 is at left, the arm is digging trench 3.

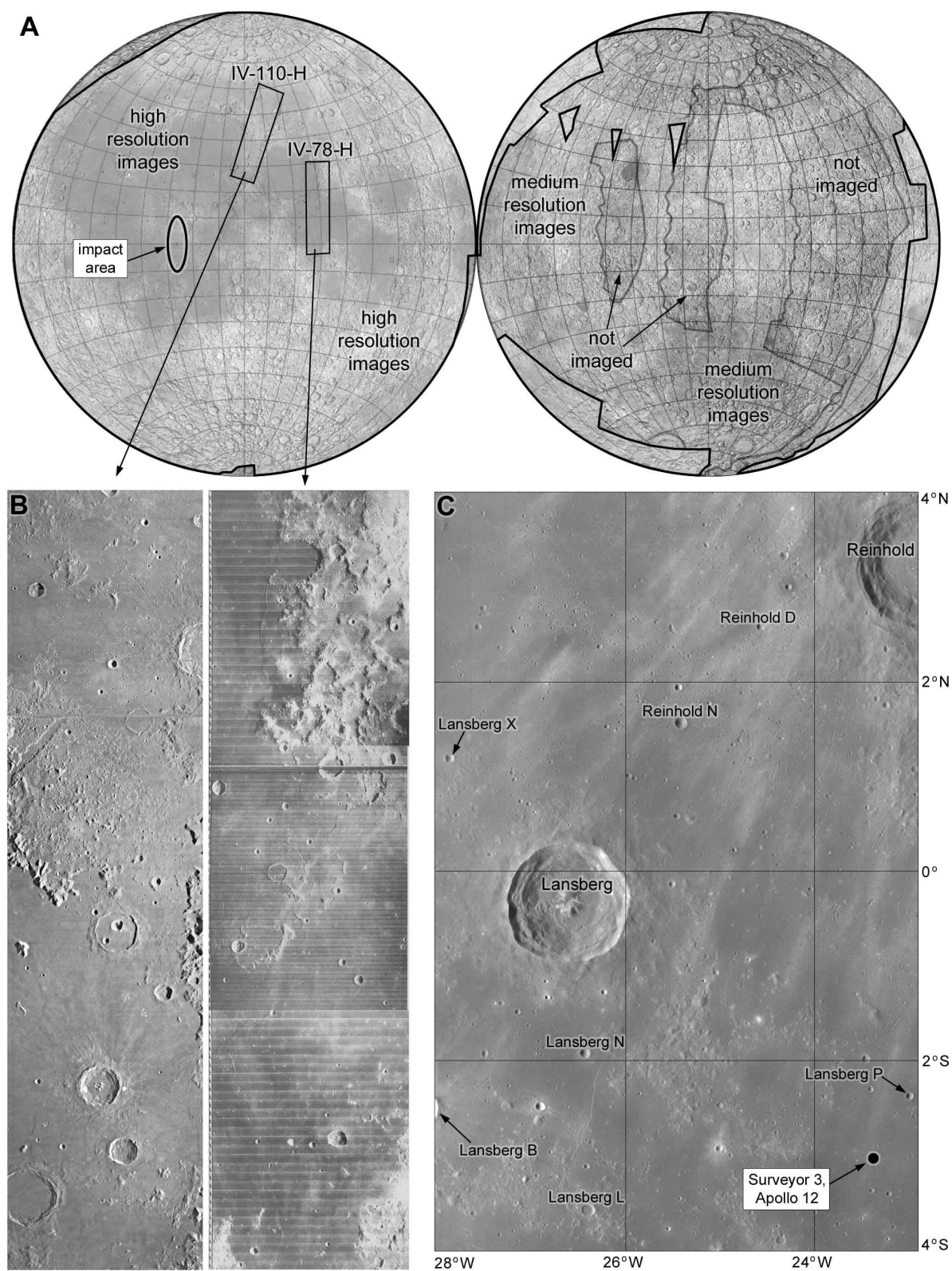


Figure 81. Lunar Orbiter 4 images and impact area. A: image coverage and impact location. B: representative Lunar Orbiter 4 images, in processed form (left) and raw form (right). C: the central part of the impact area. Lunar Orbiter 4 struck the surface in or near this region north and west of Surveyor 3.

4 May 1967: Lunar Orbiter 4

The previous Lunar Orbiters had completed the Apollo site certification imaging, so Orbiter 4's objective was changed. It was to provide systematic imaging of the entire nearside at ten times the resolution available from Earth, and to extend farside coverage. This would aid later Apollo site selection as ASSB looked beyond the Apollo Zone. Radiation and micrometeoroid data were also collected, and tracking provided gravity data beyond the equatorial regions for the first time. The 385.6 kg spacecraft was launched from Cape Canaveral at 02:25 UT on 4 May 1967, placed on a lunar trajectory and injected into a near-polar elliptical lunar orbit on 8 May. The orbit was 2706 by 6111 km, inclined 85.5° to the equator with a period of 12 hours.

All Lunar Orbiters took both roughly square medium resolution images and long narrow high resolution frames (Figure 81). Orbiters 1, 2 and 3 mapped Apollo landing areas with multiple strips of high resolution coverage. Orbiter 4 flew a mission profile in which each high resolution frame covered a latitude range of thirty degrees. Polewards of 60° north and south, 13 frames spanned the width of the nearside. Between 30° and 60° in each hemisphere, 27 frames spanned the nearside, and between the equator and 30° in each hemisphere 29 images were needed. Taken together, these images revealed the nearside more clearly than ever before.

Photography commenced on 11 May, but the camera's thermal door had trouble responding to commands from Earth to open and close. The door was left open so it would not stick in the closed position, which would prevent photography. This required careful pointing manoeuvres through each orbit to stop light leaking into the camera and fogging the film. On 13 May light leakage was observed, so the door was tested again and partially closed. The low temperatures caused by closing the door led to condensation of moisture, perhaps released from the film processing system. Solar heating, controlled by adjusting the attitude, eliminated the fogging.

Further problems with the film drive mechanism began on 20 May, so imaging ended on 26 May after 30 orbits. Despite all these problems the entire film was successfully processed and transmitted, though fogging spoiled some images. Readout ended on 1 June. The orbit was then lowered to gather gravity data to assist planning for Lunar Orbiter 5 and future Apollo missions (Hansen, 1970). The previous orbiters had revealed gravity anomalies near the equator, but Lunar Orbiter 4's near-polar orbit extended the gravity data to most of the nearside.

The 140 high resolution and 127 medium resolution frames covered most of the Moon's near side. Resolution varied from 58 to 134 m, compared with roughly 1 km which was typical of Earth-based telescopes at the time. Lower resolution images of the far side, especially the limb and southern hemisphere, were also taken. Radiation data showed that solar particle events were producing low energy protons. The spacecraft was tracked for gravity studies until the mission ended. The low point of the orbit was near the equator, and a controlled impact into Apollo Site IIP-2 in eastern Mare Tranquillitatis on 9 July was considered but not commanded. It might have provided a target for astronauts to visit. Communication was lost on 17 July, and mission operations officially ended on 16 August. Impact was predicted to occur on or before 31 October 1967 in the longitude range 22° to 30° W (Boeing Co., 1968), probably within 10° of the equator.

Figure 81A shows the areas imaged by Lunar Orbiter 4. Areas with a lighter shade portray the high resolution coverage, mostly on the nearside (left) but with small extensions into the farside. The intermediate shading is medium resolution coverage, which is of very poor quality in many areas. Darker areas were not imaged by Orbiter 4. The approximate impact area is shown at left (correcting an error in Stooke, 2007).

In Figure 81 frame IV-110-H has been processed to remove striping and artifacts as part of a project by the U. S. Geological Survey to digitize the Lunar Orbiter images (Gaddis, 2003). Further processing by the author emphasizes relief at the expense of albedo variations. A similar effort at lower resolution was undertaken by former Bellcomm employee Charles Byrne (Byrne 2005), recreating the original NASA Special Publication by Bowker and Hughes (1971). Frame IV-78-H shows the original appearance of a typical Lunar Orbiter image. Heroic efforts (Wingo, 2019) eventually retrieved the original digital data for the Lunar Orbiter images from old tapes with the last remaining tape drives capable of reading them. The data are now in NASA's Planetary Data System.

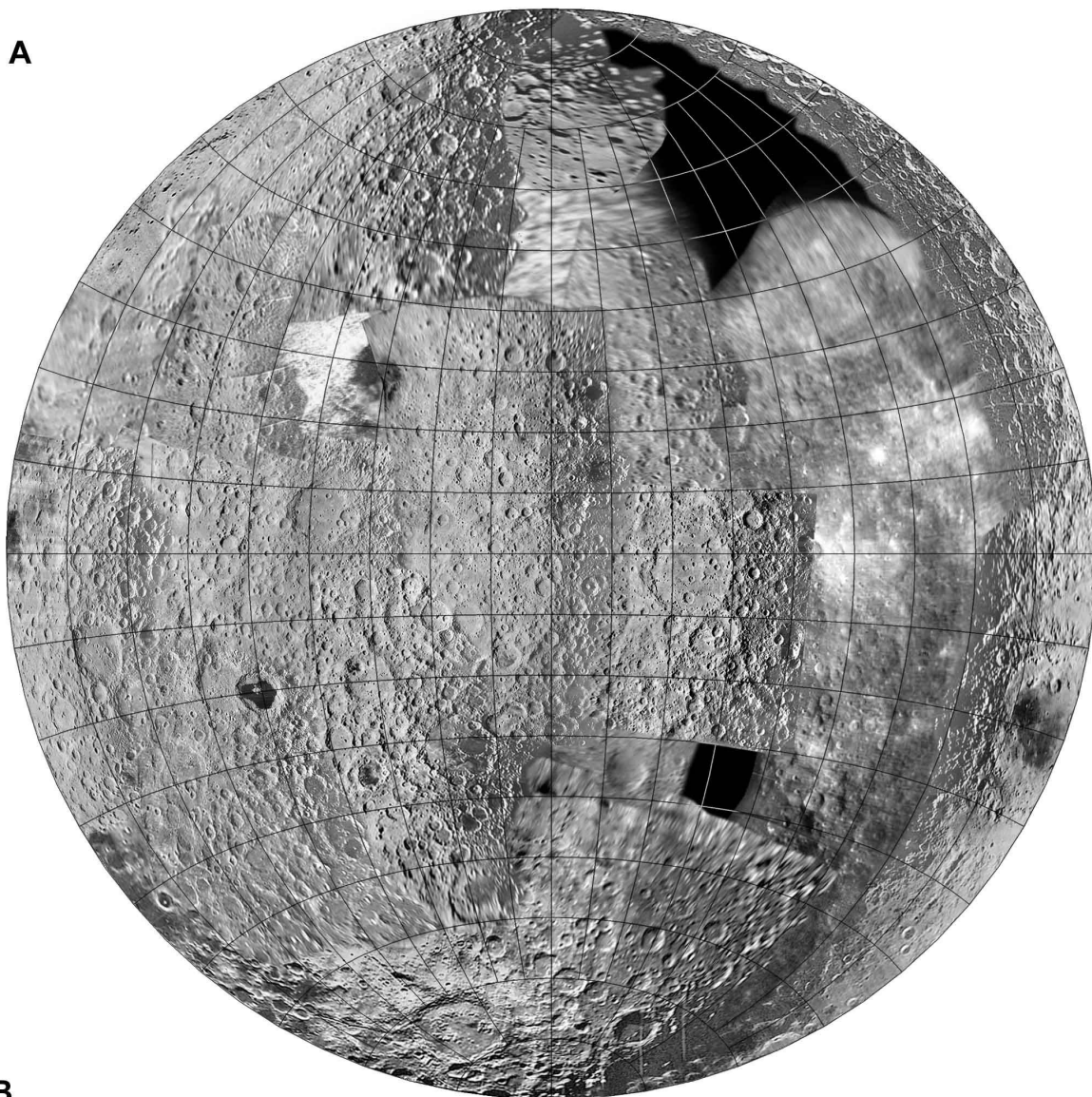
A**B**

Figure 82. Lunar Orbiter 4 images. A: Farside image coverage after Lunar Orbiter 4. This map follows Figure 72A and the sequence continues in Figure 86A. B: Lunar Orbiter 4 image IV-195-H1 of the southern edge of Mare Orientale.

Alternative missions were proposed for Orbiter 4 by NASA's Apollo Spacecraft Program Office, which had little interest in global mapping. They are described in a memorandum from Owen E. Maynard to Dr. L. Reiffel on 19 January 1967, in the JSC Archives. One option, best for Apollo zone mapping, was to cover the entire Apollo zone in medium resolution frames (about 50 m resolution) with spot coverage throughout at higher resolution. The other option, better for late Apollo planning, was medium resolution (100 m) stereoscopic coverage of the entire zone between 40° N and S, and 50° or 60° E and W, and spot coverage with high resolution frames.

Figure 82A shows the coverage of the farside up to and including Lunar Orbiter 4. The latest images were mostly of lower resolution than the Orbiter 1, 2 and 3 views, but helped to fill in many of the gaps in the farside map. Figure 82B is part of an image revealing complex tectonic structures in the Orientale basin, not suspected from the lower resolution images previously available.

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14 July 1967: Surveyor 4

Surveyor 4 was identical to Surveyor 3, including the addition of a surface sampler. It was launched at 11:53 UT from Cape Kennedy onto a very accurate lunar transfer trajectory. A midcourse trajectory correction was made 38.6 hours after launch. A normal landing sequence commenced 68 hours after launch and appeared to function flawlessly until 41 seconds after the retrorocket ignited, at 2:02:40 UT on 17 July 1967. This was 2.5 minutes before the expected landing time and about the time the retrorocket should have burned out. The altitude would have been about 15 km, after which the spacecraft should have continued its descent controlled by its small vernier engines. At that moment the radio signals from the spacecraft abruptly ceased. No explanation could be found for the failure.

According to the minutes of the 14 June 1967 meeting of the Surveyor/Orbiter Utilization Committee, the targets considered for Surveyor 4 were sites 24E-1N in Mare Tranquillitatis, 4E-5S on highland plains in Hipparchus crater, and 1W-1N in Sinus Medii (see Table 15, Figure 36). 1W-1N in Sinus Medii was selected for this mission. It was also the target of Surveyor 2 and a strong candidate for an Apollo landing site. The original pre-launch target was a 30 km circle centred at 0.58° N, 0.83° W, almost identical to the post-launch adjusted target for Surveyor 2. If no midcourse correction or braking had been attempted, impact would have been at 1.99° S, 5.9° W (Figure 54C). The final aim point was moved by the midcourse correction to 0.417° N, 1.333° W, within a 7.2 by 10.8 km ellipse made feasible by the extremely accurate trajectory.

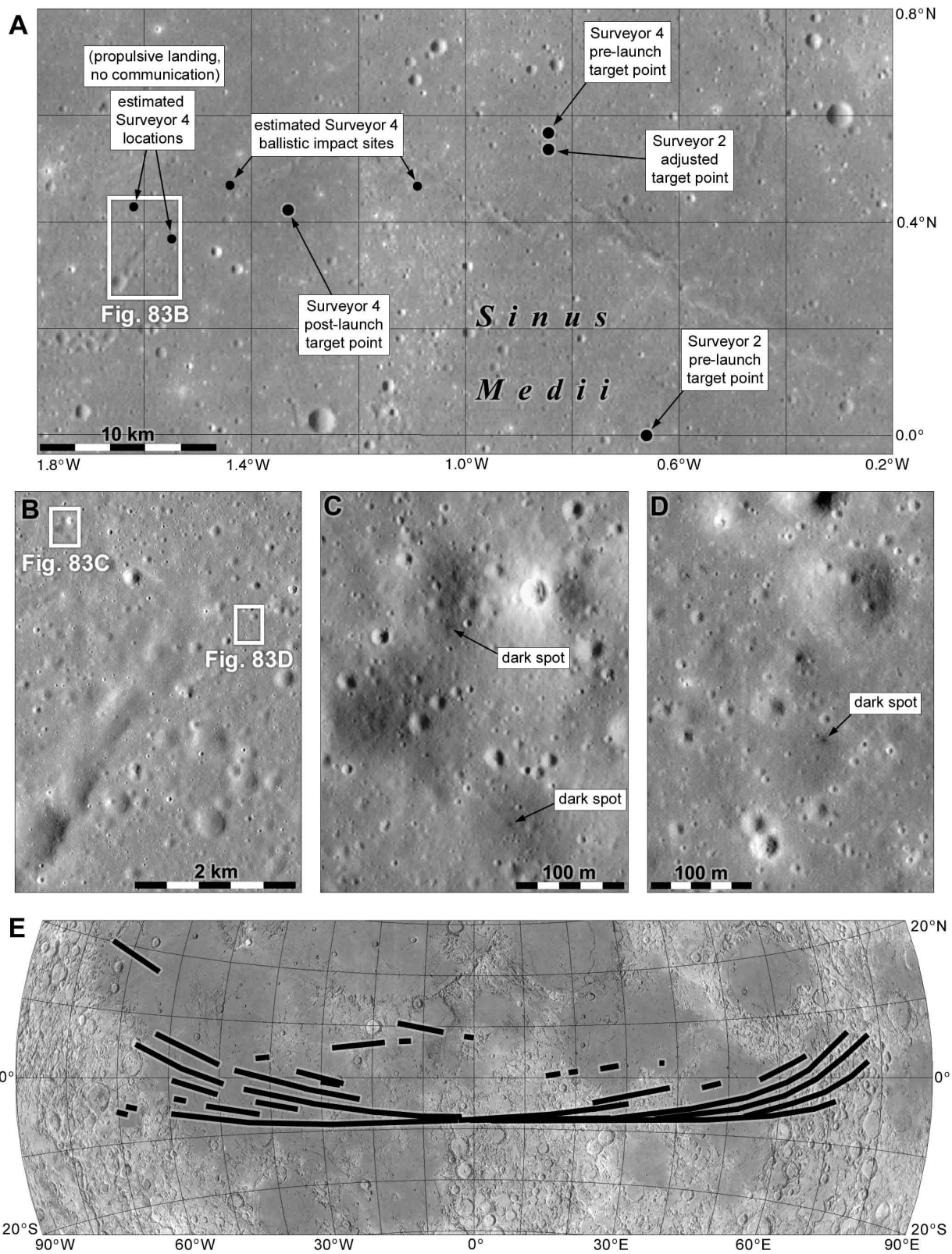


Figure 83. Surveyor 4 and Explorer 35. A: Surveyor 4 target and crash sites. B, C, D: two locations with dark spots near the possible landing or impact sites of Surveyor 4, which have NOT been verified. E: bistatic radar reflections from Explorer 35. Surface slope and roughness could be estimated along these tracks.

The estimated Surveyor 4 landing point (assuming safe final braking and landing, but total loss of telemetry) is 0.43° N, 1.62° W (NSSDCA also says 0.37° N, 1.55° W). It is more likely that Surveyor 4 crashed nearby (JPL, 1968). NSSDCA gives locations of 0.47° N, 1.44° W or 0.469° N, 1.086° W for a ballistic crash (unpowered after loss of signal). These locations are shown in Figure 83A. Figures 83B-83D show possible candidates for small dark surface markings associated with the mission, near the safe landing points. These have not been verified but show how evidence of the landing might be sought in LRO images. NSSDCA also suggests that the retrorocket might have exploded, destroying the spacecraft and scattering debris but perhaps not leaving any obvious marking on the surface.

JPL 1968. *Surveyor IV mission report*, JPL Tech. Rep. 32-1210. Pasadena: Jet Propulsion Laboratory.



19 July 1967: Explorer 35 (IMP-E)

Explorer 35 was a 230 kg (fueled mass) spin-stabilized spacecraft intended for space science research at lunar distances. It was built by Westinghouse and managed by the Goddard Space Flight Center, in Maryland. Explorer 35 was launched on a Delta booster from Cape Canaveral at 14:19 UT and entered a 485 by 675 km lunar orbit inclined 32° to the equator with a 96 minute period. The spacecraft rotated at 25.6 rpm about an axis nearly perpendicular to the ecliptic plane. An alternate designation, IMP-E (or AIMP-E) derives from its formal title, ‘(Anchored) Interplanetary Monitoring Platform’.

Explorer 35 studied plasma, dust, magnetic fields, energetic particles, and solar X-rays, but it also obtained some lunar data. Bistatic radar observations of areas mostly within 10° of the lunar equator between longitudes 80° E and 70° W (Figure 83E) were made as transmissions from the spacecraft were scattered from the lunar surface and then recorded at the 45 m Stanford dish antenna. The results gave statistical information on small scale slopes and roughness in those areas (Tyler and Simpson, 1970). The data did not contribute much to the study of individual Apollo sites but added to a general understanding of the nature of the lunar surface. The spacecraft was turned off on June 24, 1973 after 6 years of successful operation. According to Powell (2003), Explorer 35 is probably still in lunar orbit.

Powell, D., 2003. The Moon’s own moons. *Astronomy Now*, v. 17, no. 9, September 2003, pp. 38-39.
Tyler, G. L. and Simpson, R. A., 1970. Bistatic Radar Measurements of Topographic Variations in Lunar Surface Slopes with Explorer 35. *Radio Science*, v. 5, no. 2, pp. 263-271.



01 August 1967: Lunar Orbiter 5

Lunar Orbiter 5, the last Lunar Orbiter mission, was launched from the Eastern Test Range at 22:32 UT. On 5 August the spacecraft was placed in a 195 km by 6023 km lunar orbit inclined 85° to the equator with a period of 8.50 hours. On 7 August the low point was dropped to 100 km and on 9 August the orbit was adjusted to 99 km by 1499 km with a 3.16 hour period. Photography took place from 6 to 18 August. The mission goal was to photograph candidate Apollo sites on the nearside (Figure 84A), including a few Apollo zone sites which needed additional data (Figure 84B) and later Apollo sites outside the narrow zone previously considered. Lunar Orbiter 5 also filled in the blanks in farside coverage (Figures 85A, 86A). Orbiter 5 obtained 211 medium and high resolution

image pairs including a full Earth image from lunar orbit. It collected radiation intensity and micrometeoroid data and was used to evaluate Apollo tracking stations and orbit determination methods.

Loss of attitude control gas resulted in a decision to command an impact on the nearside while the spacecraft could still be controlled. The targeted impact point was at 4.35° S, 83.17° W, and the impact was estimated to have occurred at 2.79° S, 83.04° W, northeast of the Orientale basin near the crater Schluter at 07:58 UT on 31 January 1968 (Boeing Co., 1968). Figure 87A shows the estimated impact site of Lunar Orbiter 5.

The Orbiter 5 nearside targets were candidate Apollo sites, including scientifically interesting targets outside the equatorial zone. Some sites frequently mentioned as future sites are labelled in Figure 84A. One set of oblique images showed oblique astronaut-eye approach views of the Apollo sites in Mare Tranquillitatis favoured for the first landing. Two areas on the eastern limb were extensions of medium resolution farside coverage. Lunar Orbiter 5 essentially completed the reconnaissance of the farside. The goal of farside imaging was to fill gaps in previous coverage, and this was largely achieved. Some areas in the extreme east of the farside near the Orientale basin were seen poorly, at oblique angles and very near the terminator with some areas hidden in shadow. Otherwise excellent high resolution coverage was obtained across the northern and eastern farside. A few major features are labelled in Figure 85A, with an example of one of these images showing Mare Moscoviense near the limb (Figure 85B). Cumulative coverage of the farside is shown in Figure 86A. The only area remaining unseen by any spacecraft at this time was a narrow strip at longitude 105° W, from the outer rim of the Orientale basin to the south pole, which was eventually imaged by Clementine. Figure 86B is a sample Lunar Orbiter 5 image showing the floor of Copernicus near its central peak, one of many candidate Apollo landing sites imaged in detail by this mission.

Tracking of the Lunar Orbiters and the Soviet Luna 10, 11 and 12 orbiters revealed local variations in the lunar gravitational field (Figure 84C). Areas where mass concentrations (mascons) caused higher accelerations are shown with brighter shading, especially over the Imbrium and Serenitatis basins. Weaker gravitational anomalies are also seen over the circular mare basins Crisium, Nectaris and Humorum, but not over the irregular maria (Tranquillitatis, Nubium, Fecunditatis, Oceanus Procellarum). These ‘mascons’ (mass concentrations) were once thought to be evidence of buried asteroids but are now explained by the thick stack of basalt layers filling the deepest parts of these impact basins. The irregular mare areas are generally thinly covered ‘overflow’ areas, as shown by the large number of protruding crater rims and isolated hills. Figure 84C is adapted from Muller and Sjogren (1968).

The five Lunar Orbiter missions are summarized by Levin *et al.* (1968) and Byers (1977). Their images are described and illustrated by Hansen (1970) and Kosofsky and El-Baz (1970). Data collected during the Lunar Orbiter program included 22 micrometeoroid impacts (Gurtler and Grew, 1968), showing that the average dust particle flux near the Moon was about a hundred times greater than in interplanetary space but about half of the level near Earth. The radiation experiments showed that the Apollo hardware would protect astronauts from typical levels of solar particle radiation, but not from major solar flares.

Boeing Co., 1968. *Lunar Orbiter V: extended mission spacecraft operations and subsystem performance*.

NASA Contractor Report CR 1142, Boeing report D2-100755-4. Seattle, Washington: Boeing Co.

Byers, B. K., 1977. *Destination Moon: A History of the Lunar Orbiter Program*, NASA TM X-3487 (Washington DC).

Gurtler, C.A. and Grew, G.W., 1968. Meteoroid hazard near Moon. *Science*, v. 161, no. 3840, pp.462-464. DOI: 10.1126/science.161.3840.462

Hansen, T. P., 1970. *Guide to Lunar Orbiter Photographs*. NASA SP-242. Washington, D. C., National Aeronautics and Space Administration.

Kosofsky, L.J. and El-Baz, F., 1970. *The moon as viewed by Lunar Orbiter*. NASA Special Publication 200. Washington, D.C.: National Aeronautics and Space Administration.

Levin, E., Viele, D. D. and Eldrenkamp, L. B., 1968. The Lunar Orbiter missions to the Moon. *Scientific American*, v. 218, no. 5, pp. 58-82. <https://www.jstor.org/stable/10.2307/24926229>

Muller, P. M. and Sjogren, W. L., 1968. Mascons: lunar mass concentrations. *Science*, v. 161, pp. 680-684.



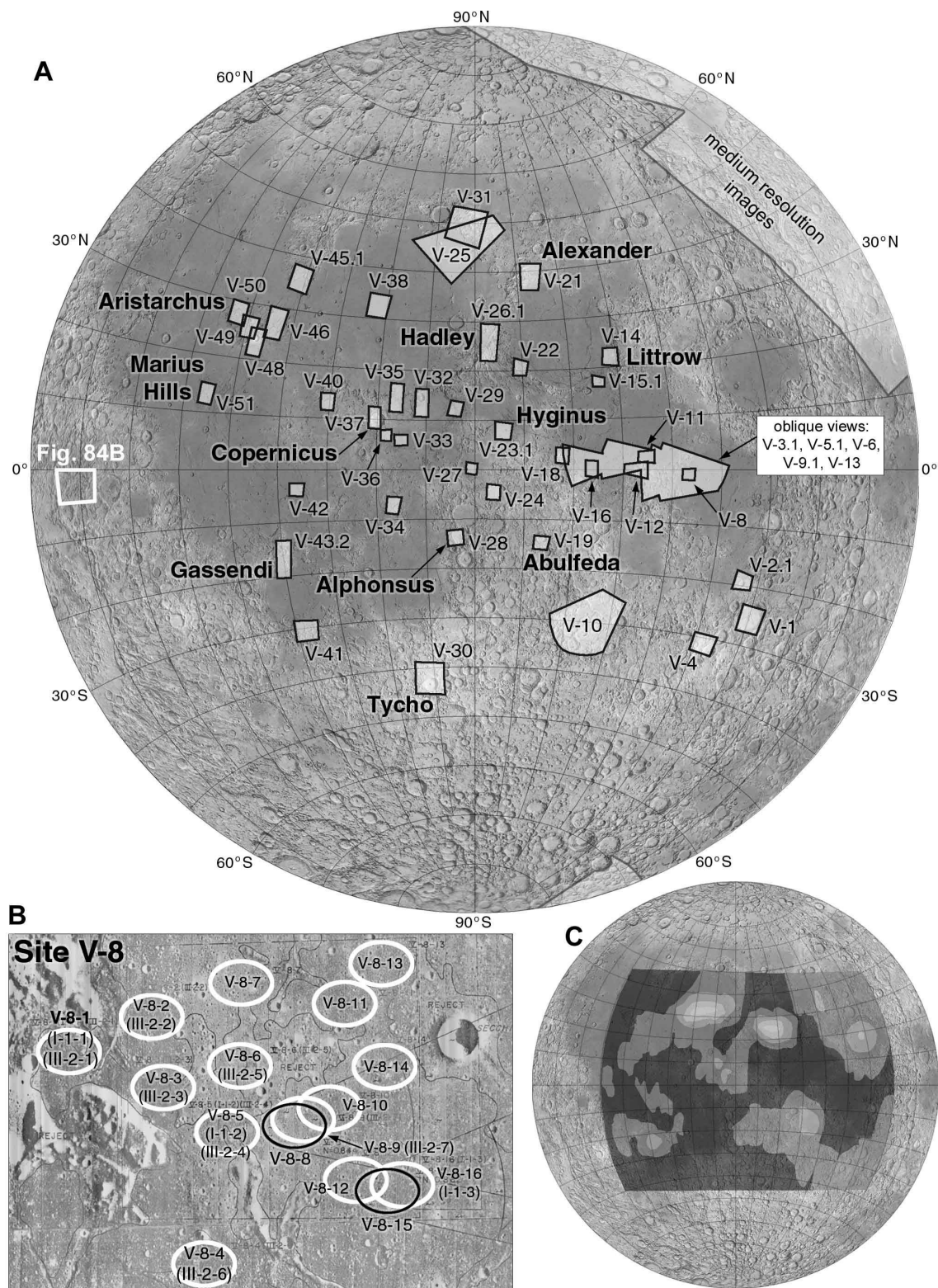


Figure 84. Lunar Orbiter 5 nearside data and site screening results. A: nearside imaging sites. B: site screening for one site in the Apollo zone. The black ellipses were preferred. C: Gravity anomalies compiled from Lunar Orbiter spacecraft tracking. Lighter shades represent stronger gravity over circular maria (Muller and Sjogren, 1968).

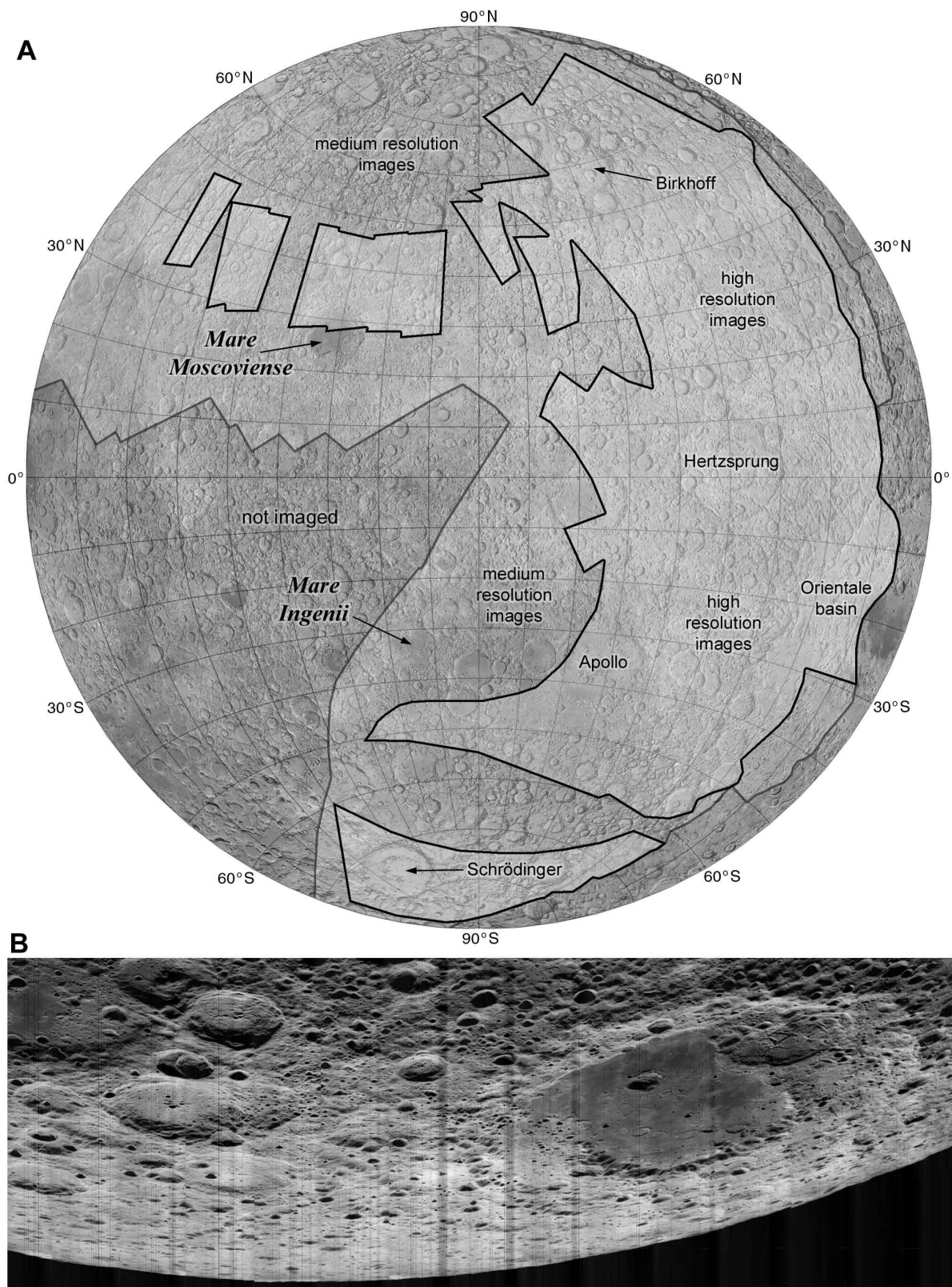


Figure 85. Lunar Orbiter 5 farside images. A: farside image coverage. B: part of Lunar Orbiter 5 image V-085-M showing Mare Moscoviense at right (north at the left).

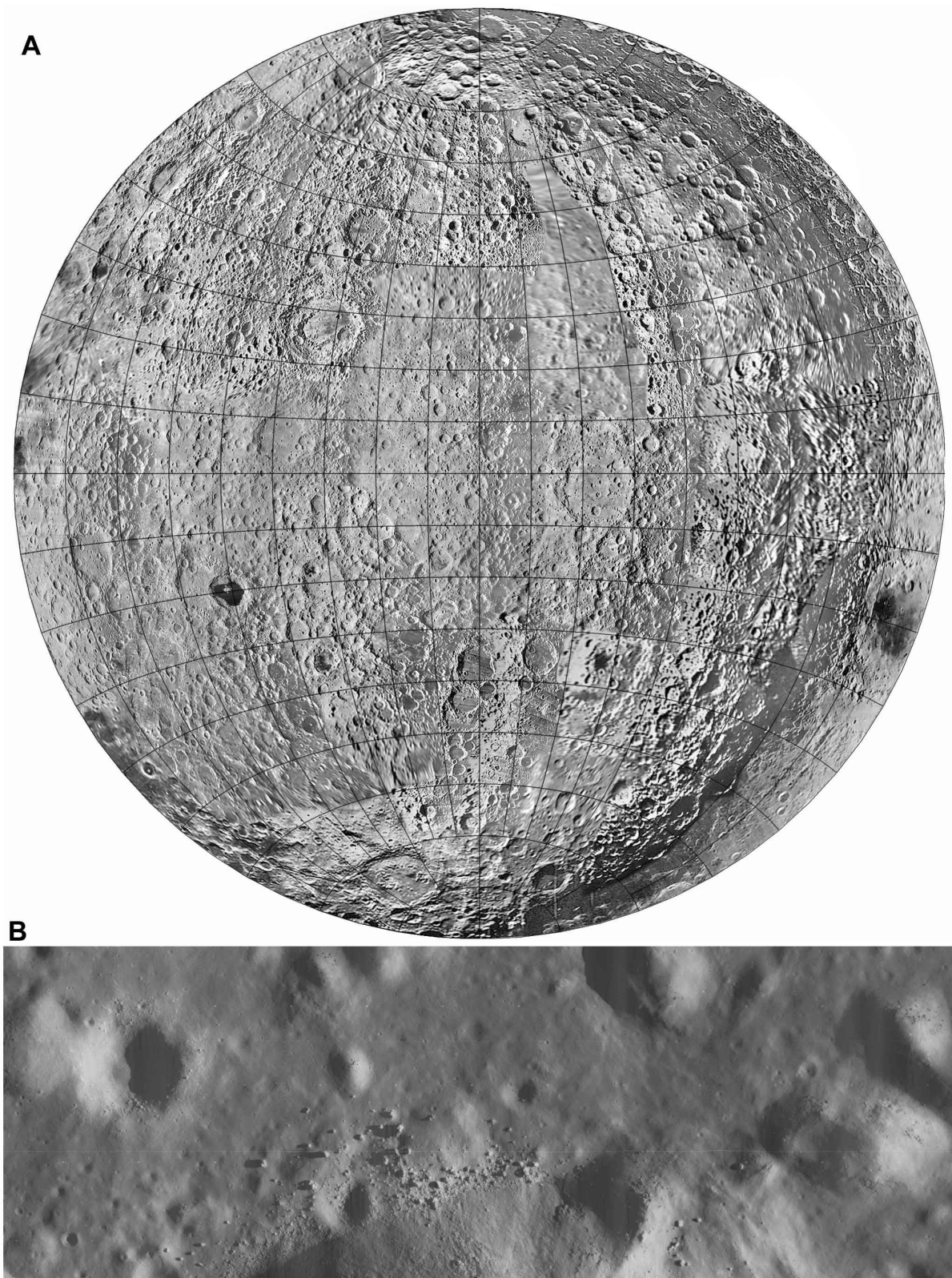


Figure 86. Lunar Orbiter 5 images. A: Farside image coverage after Lunar Orbiter 5. This map follows Figure 82A and the sequence will continue with the Clementine mission. B: part of Lunar Orbiter 5 image LO5-152-H1 of the floor of Copernicus including the base of the central peaks, a potential Apollo landing site.

1967: Lunar Orbiter 5 Site Screening

Lunar Orbiter 5 images were primarily designed to search for later Apollo scientific sites, but several sequences provided additional data for planning the first landings. The detailed screening procedures adopted for previous Lunar Orbiter primary sites (Figures 53, 59, 73) were followed initially for only one of the Orbiter 5 sites, V-8, which was the same as sites IP-1 and IIIP-2 (Lunar Orbiter Photo Data Screening Group, 1968). The results are shown in Figure 84B. Two satisfactory ellipses (black) were identified among the 16 candidates. Some ellipses in that map which are given multiple designations had also been assessed in previous screening efforts. Apollo planners now had numerous choices for early landing sites, and the Lunar Orbiter program had proven highly effective.

Lunar Orbiter Photo Data Screening Group, 1968. *A preliminary geologic evaluation of areas photographed by Lunar Orbiter V including an Apollo landing analysis of one of the areas*, Langley Working Paper LWP-506, February 1968.



1967: Apollo EVA planning

As site selection continued, lunar surface exploration capabilities were also being assessed. Harrison Schmitt had sketched an astronaut walking route on a Ranger photograph (Figure 27B), showing how visits to features of geological interest (craters of different sizes and ages, clusters of boulders) could be pre-planned and trained for. Similar work could now be done with Lunar Orbiter images in screened Apollo landing ellipses.

Figure 87C shows an example of this from ellipse II-5-3 in site IIP-5 (identified in Figure 59, very close to the Ranger 8 impact site), presented by J. Sasser at the ASSB meeting on 15 December 1967 (based on NASA graphic S-67-13508). The ellipses are 7.9 km long, for scale. Figure 87D illustrates a possible EVA originally plotted on a composite of Lunar Orbiter 2 images II-069-H1 and H2, but here drawn on an LROC NAC mosaic. Numbers indicate sampling locations. Preplanning like this was only feasible if the LM could be brought down within walking distance of a specific target, which was not expected for the first landing.



August 1967: Santa Cruz Study

The 1967 Summer Study of Lunar Science and Exploration, organised by MSC and directed by Wilmot Hess, was held from 31 July to 13 August 1967 at the University of California Santa Cruz (MSC, 1967). Its objectives were to plan future lunar exploration, to prepare detailed mission plans and scientific investigations, and to assess equipment needs.

These guidelines were developed prior to the 1968 Appropriation Hearings in Congress which curtailed future spending, and a prolonged post-Apollo exploration program was still anticipated at the time. The resulting plans far exceeded NASA's ability to accomplish them.

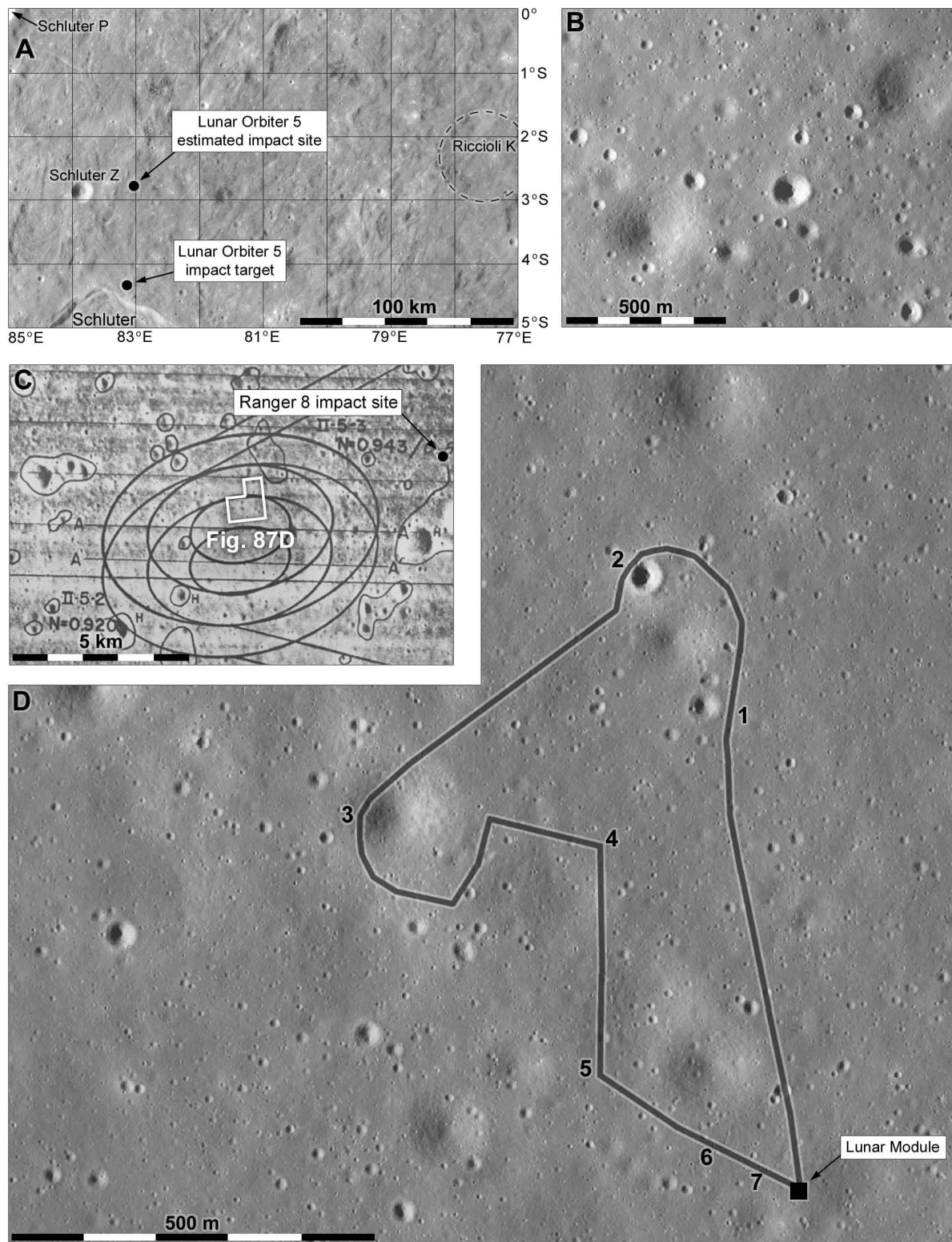


Figure 87. Lunar Orbiter 5 impact and contemporary Apollo planning. A: Lunar Orbiter 5 impact area. B: detail of LROC image M102701722R showing the approximate location of the impact site. C: detail of Figure 59, site IIP-5 showing the location of Figure 87D. D: example of an EVA presented to ASSB by J. Sasser on an LRO image base.

The report of the meeting consists of sections by working groups for geology, geophysics, geochemistry and other disciplines, and a summary by the Group for Lunar Exploration Planning (GLEP) chaired by Hess. These are summarized in Table 27 and illustrated in Figure 88.

Santa Cruz results included detailed plans for missions to Alphonsus, Aristarchus and Copernicus. They emphasised the need for broad surface mobility, including a one-person Lunar Flying Unit (LFU) and the Local (or Lunar) Scientific Survey Module (LSSM), a long-range rover capable of carrying crew and being operated between missions by remote control. Three exploration phases were anticipated: (1) early Apollo (the first few landings, local exploration on foot); (2) the Apollo Applications Program (AAP), using enhanced lunar modules, LFU and LSSM mobility, and dual launches in which equipment including an LSSM could be landed initially, followed by crew on a second Saturn 5; and (3) a transition phase (late Apollo or early AAP) involving some increases in stay time and mobility but only single launches.

Landings would occur at roughly six month intervals between 1970 and 1975. AAP missions could include lunar orbit flights, with crew, for from one to twelve months. In some dual-launch missions a remote-controlled LSSM would make long traverses, deploying geophysical instruments and collecting samples, ending at the next landing site where astronauts would retrieve the samples. Augmented or 'Block II' Surveyors would take instruments to places where people would not land. Most of these ideas were soon abandoned and AAP evolved into the Earth-orbital Skylab program.

The geology, geophysics and geochemistry groups at the Santa Cruz meeting each developed separate plans for lunar exploration. The Group for Lunar Exploration Planning (GLEP) attempted to reconcile the different views and provide a single summary plan. In addition, detailed exploration plans for three sites were included in the meeting report. These are all summarized in the following pages.

Figure 88A shows the sites suggested by GLEP in its summary of the Santa Cruz meeting (Table 27). Black circles indicate proposed AAP landing sites. Black lines represent the long distance LSSM rover routes, controlled from Earth between AAP landings. White circles indicate sites suitable for late Apollo missions or additional early AAP single launches with LFU mobility if the dual launch capability was delayed. These late Apollo or early AAP sites are listed in Table 28. Four of these sites (marked with asterisks in Table 28) were indicated as most suitable for late Apollo, with its more limited mobility.

Figure 88B shows the sites suggested by the Geology working group at Santa Cruz. The black circles with names in boxes are the AAP landing sites listed in Table 27. EA1 is Early Apollo 1. Black lines show the LSSM routes described in Table 27. White circles represent nine additional sites suitable for late Apollo missions. GLEP combined those sites and two other Geology group choices to make their late Apollo/early AAP list (Table 28). White lines with names in white text represent a set of alternate LSSM routes discussed at the meeting but not included in the final working group recommendations. Mare Orientale was also discussed as a major objective for AAP. A minimum of three dual launches would be required for adequate coverage.

Figure 88C shows the AAP sites suggested by the Geophysics working group. Copernicus and Hyginus were single launch sites. The other proposed sites involved dual launches with a LSSM which would be used by the crew during the 14 day mission, and then driven from Earth for a traverse of up to 1000 km lasting about six months. Most of these remotely driven LSSM routes terminated at the next landing site, after deploying instruments and collecting samples along the way. The next crew would then collect the samplers and use the rover during their mission. The AAP landings would be interspersed with automated landers (Augmented Surveyors, AS, shown as white circles on the map), which would carry instruments to the additional sites listed in Table 29.

Table 27. Mission sequences developed for the Santa Cruz meeting.

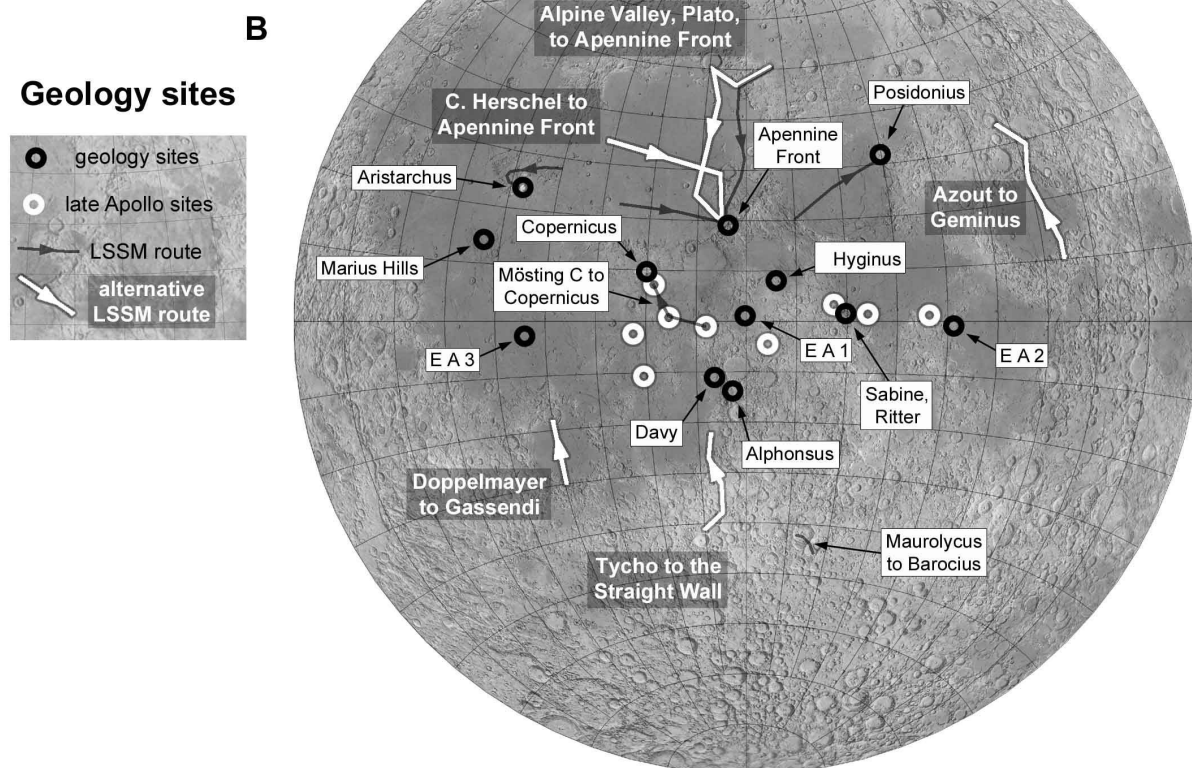
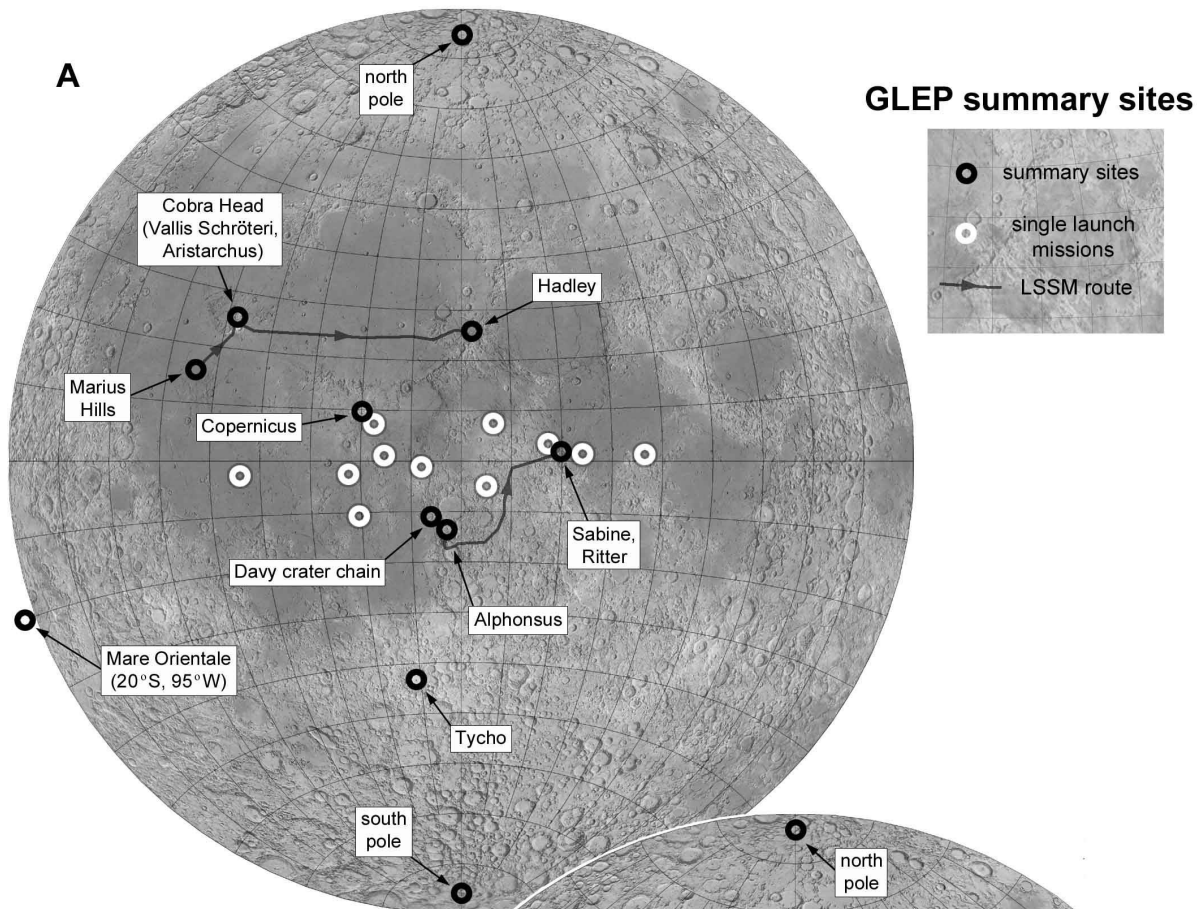
Mission		GLEP Summary (Figure 88A)	Geology group (* can be modified as late Apollo mission) (Figure 88B)	Geophysics group (Figure 88C)	Geochemistry group (Figure 88D)
Early Apollo	1		Sinus Medii	at least two mare sites	
	2		Mare Fecunditatis, site I-A-3		
	3		Flamsteed, site II-12-B *		
AAP-1		orbital remote sensing	Copernicus peaks *	Copernicus floor	Davy
AAP-2		Copernicus peaks	Hyginus * or Davy	Hyginus	Copernicus peaks
AAP-3		Davy	Marius Hills *	North Pole	Marius Hills
AAP-4		Copernicus walls	Sabine and Ritter *	Marius Hills	Copernicus wall
AAP-5		Marius Hills (LSSM to Cobra Head)	LSSM from Mosting C to Copernicus (no astronaut rendezvous)	orbital remote sensing	Aristarchus
AAP-6		Cobra Head (LSSM to Hadley Rille)	North Pole	Aristarchus (LSSM to Apennine Front)	Alphonsus
AAP-7		orbital remote sensing	LSSM from Maurolycus to Barocius (no astronaut rendezvous)	Apennine Front (LSSM to Sabine and Ritter)	Tycho
AAP-8		Alphonsus (LSSM to Sabine and Ritter)	LSSM from Montes Harbinger to Aristarchus	Sabine and Ritter (LSSM to Mare Fecunditatis)	North Pole
AAP-9		Sabine and Ritter (or end of LSSM route)	Aristarchus	Alphonsus (LSSM to eastern highlands)	
AAP-10		landings at one of the poles, Tycho, Mare Orientale and Hadley Rille, order uncertain.	LSSM at Alphonsus	orbital remote sensing	
AAP-11			Alphonsus *	orbital, subsatellites	
AAP-12			LSSM from Sulpicius Gallus to Posidonius		
AAP-13			Posidonius		
AAP-14			LSSM Alpine Valley to Apennine Front		
AAP-15			LSSM Mare Imbrium to Apennine Front		
AAP-16			Apennine Front		

Table 28. Late Apollo/Early AAP sites from the Santa Cruz meeting	
site name	location
Copernicus H *	7° N, 18° W
Gambart *	1° N, 15° W
Mösting C *	2° S, 8° W
Hyginus Rille	8° N, 6° E
Flamsteed (Surveyor 1)	3° S, 43° W
Dionysius east flank	3° N, 17° E
Hipparchus	5° S, 4° E
dome near II-P-2 *	2° N, 34° E
Ranger 7	10.6° S, 20.6° W
Ranger 8	2.7° N, 24.6° E
Surveyor 3	3.2° S, 23.4° W
* sites most suitable for late Apollo (pre-AAP) missions with limited mobility	

Table 29. Augmented Surveyor sites from the Santa Cruz meeting		
number	target	location
AS-1	south polar region	75° S, 0° E
AS-2	far eastern highlands	3° S, 70° E
AS-3	southeastern highlands	35° S, 50° E
AS-4	Sinus Roris near Repsold	50° N, 70° W
AS-5	far western highlands	10° S, 70° W
AS-6	possibly sent to farside sites	
AS-7		
AS-8		

The Geophysics group also recommended that the AAP 5 orbital mission (Table 27) deploy ten semi-hard landers including seismometers (advanced versions of the Ranger 3, 4 and 5 capsules) at the locations shown in Table 30 (small black squares on Figure 88C). Saturn IVB upper stage impacts from each subsequent AAP flight would generate seismic signals for the network. The seismometers form a long array running southwest to northeast across the nearside, a shorter array across the southern highlands, and a local array in Mare Serenitatis.

Table 30. AAP 5 hard-lander sites from the Santa Cruz meeting			
45° N, 60° E	north of Crisium	18° N, 18° E	south Serenitatis
20° N, 26° E	east Serenitatis	25° N, 20° E	central Serenitatis
0° N, 0° E	Sinus Medii	25° S, 35° W	Mare Humorum
40° S, 70° W	west of Schickard	10° S, 10° E	central highlands
30° S, 10° E	southern highlands	50° S, 10° E	southern highlands



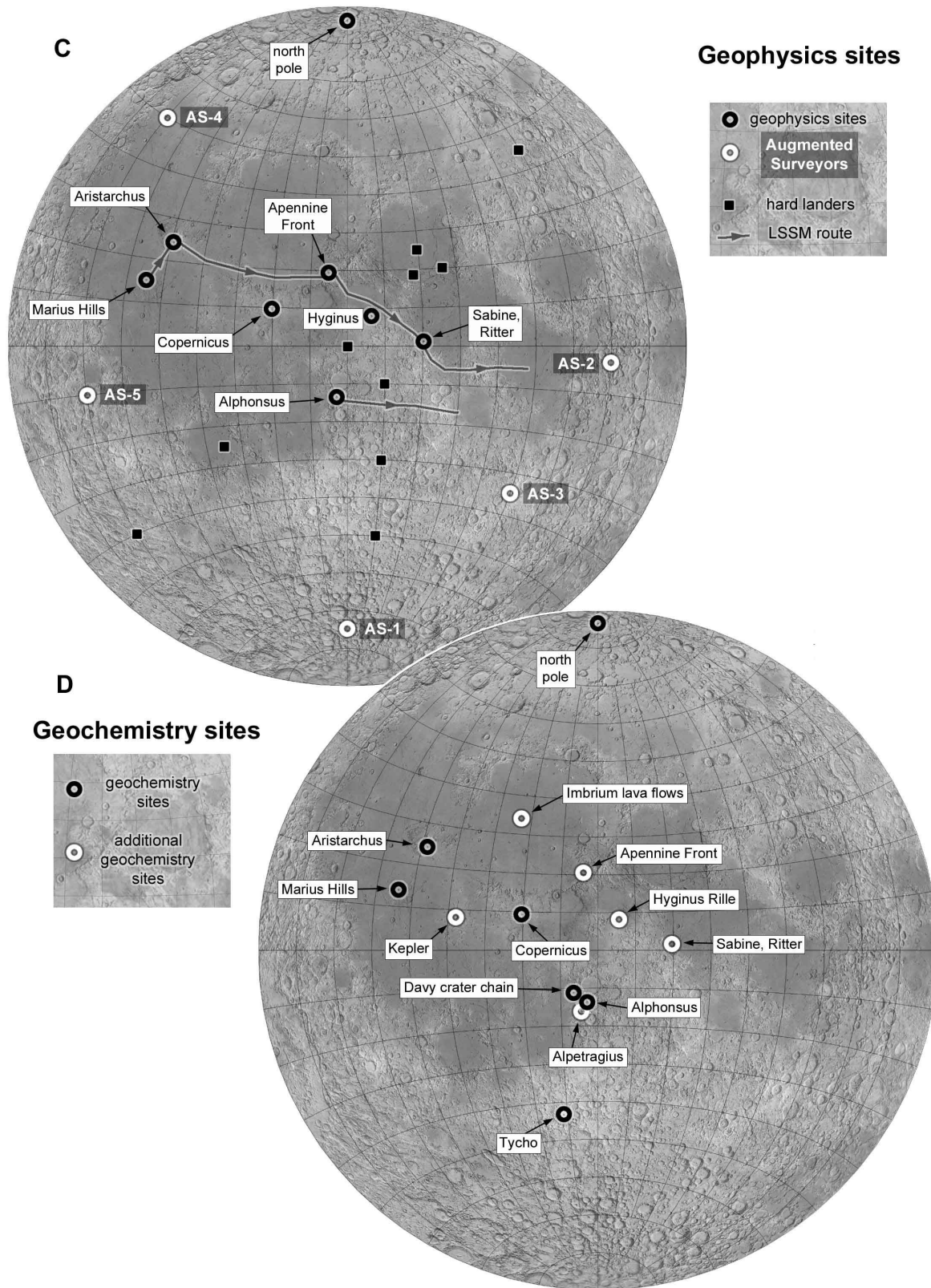


Figure 88 (both pages): Santa Cruz exploration plans. A: GLEP summary. B: Geology working group. C: Geophysics working group. D: Geochemistry working group.

Figure 88D presents the Geochemistry working group plans (Table 27). They identified a list of sites (black circles) which were expected to provide materials of different composition, including fresh impacts into mare and highland targets and volcanic materials with different characteristics. At the time the Davy crater chain was thought to be volcanic, though today it would be considered an impact feature. The white circles indicate other sites considered by the group. The working group also promoted a program of orbital remote sensing.

Two detailed plans for exploration of the Copernicus central peaks were described at the Santa Cruz meeting. Figure 89A shows the landing area within the 90 km diameter crater, just north of the central peaks. Figure 89B depicts two sets of LFU excursions extending from slightly different landing sites. Black lines show the Geochemistry working group's plan for three excursions to sites on the peaks and the crater floor, and white lines show the Geology working group plan for four trips, including two with LFU flying units to the tops of different peaks. Small dots on both sets of routes are the proposed study and sampling sites. These missions would have required a minimum of three days on the lunar surface.

The geologically complex Aristarchus - Schröter's Valley (Vallis Schröteri) area (Figure 89C) was always a favoured target, though it was not visited by astronauts or robotic missions. The southeastern end of the valley is informally known as the Cobra Head, apparently the vent from which lavas erupted to carve the valley. It has often been associated with reports of continuing activity (Kopal and Carder 1974, p. 159). The exploration plan is shown in Figure 89D. The dark line extending to the south from the landing site shows the path of a remote-controlled LSSM traverse after the Cobra Head mission, continued in Figure 89C to the rims of Herodotus and Aristarchus. It would collect samples on its way to the Hadley AAP site (Figure 88A). An alternative version of activities at the Cobra Head was described by the Geochemistry group. Their crew would drive the LSSM for a three day excursion, including LFU sorties into and across the valley.

Figure 90A depicts activities at Alphonsus, including remotely controlled LSSM traverses before and after the crew visit. At the western instrument station the LFU would be used for two sorties into presumed volcanic deposits around a dark halo crater. Samples of that material and of the crater walls would have been collected by the LSSM before the crew arrived. After the crew visit the LSSM would be driven around the crater and out of it to continue on the path illustrated in Figure 88A, leading to the next crew target at Sabine and Ritter in Mare Tranquillitatis.

Kopal, Z. and Carder, R. W., 1974. *Mapping of the Moon*. Dordrecht: D. Reidel Publishing Company.
MSC, 1967. *1967 summer study of lunar science and exploration*. NASA SP-157. Washington, D.C.: National Aeronautics and Space Administration.



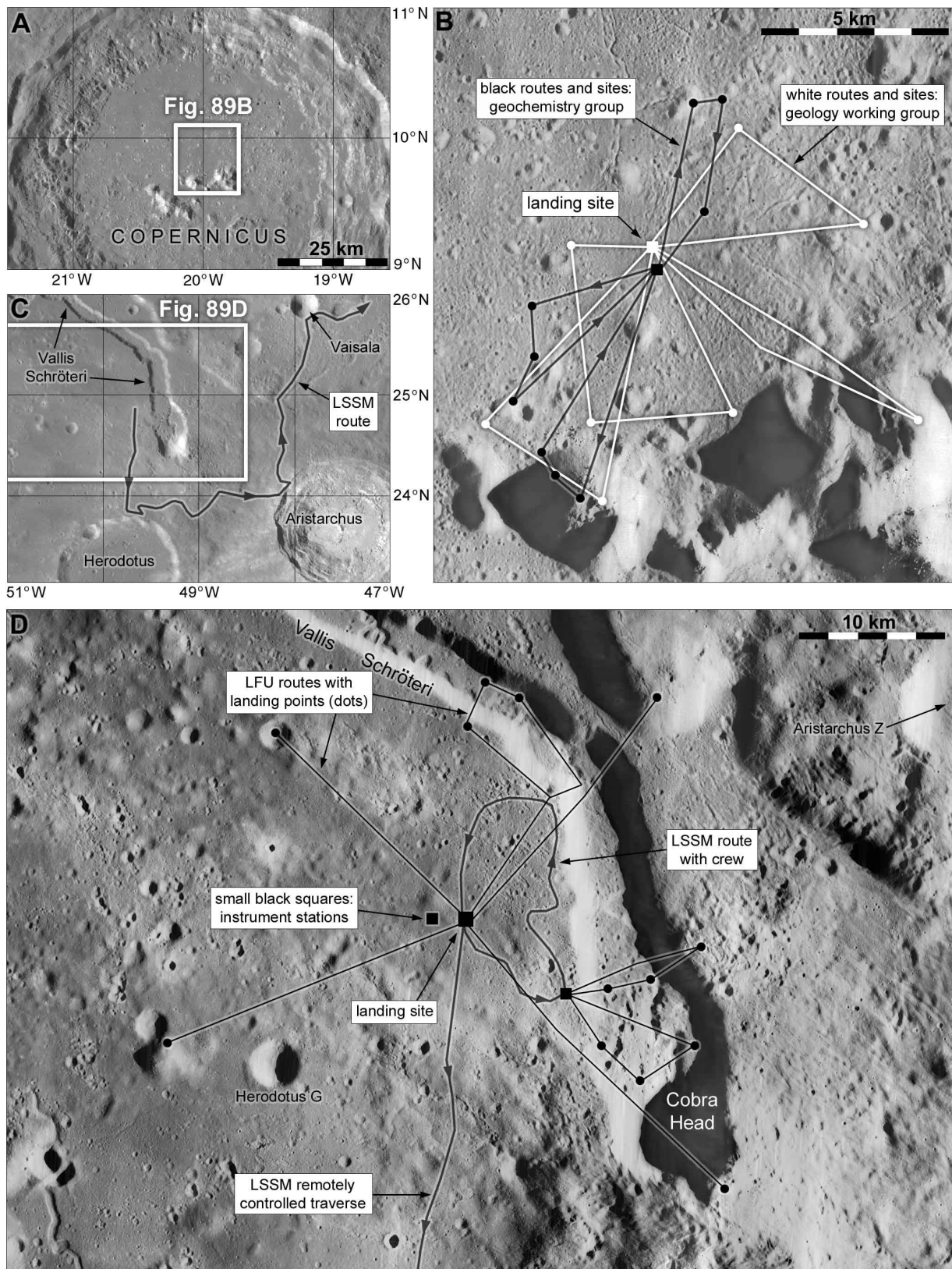


Figure 89. Santa Cruz exploration plans. A, B: Copernicus peaks. The base image is Lunar Orbiter 5 frame V-151-M. C, D: Aristarchus Plateau (Cobra Head). The base image is Lunar Orbiter 5 frame V-202-M.

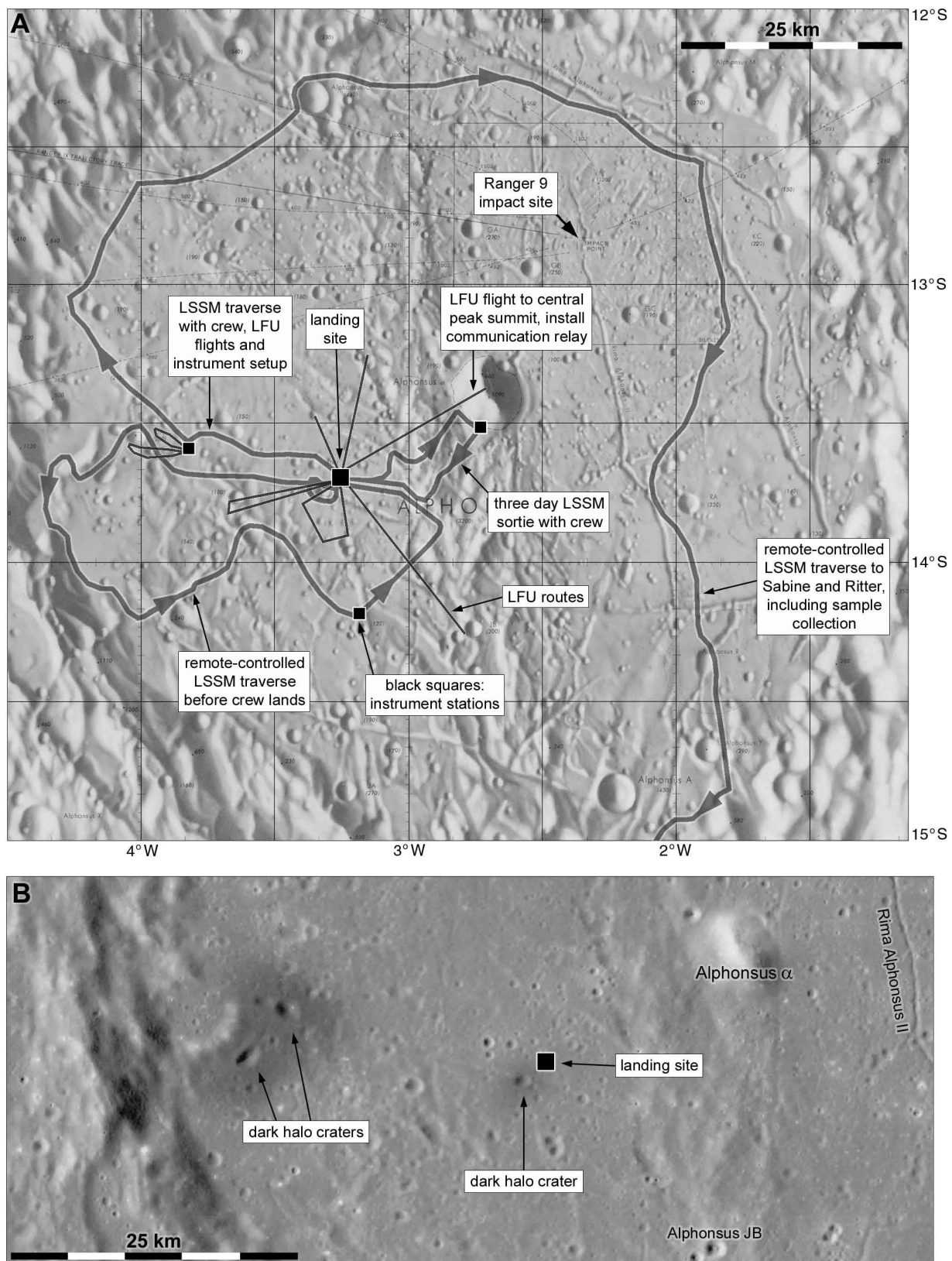


Figure 90. Santa Cruz exploration plan for Alphonso. A: Activities in Alphonso crater, drawn on the same base as Figure 28B. B: enlarged view of the landing site (LROC wide angle mosaic) with nearby dark halo craters.

08 September 1967: Surveyor 5

This spacecraft was similar to Surveyors 3 and 4 except that the surface sampler was replaced with an alpha-particle backscatter instrument to measure the proportions of various elements in the regolith grains. A small bar magnet was attached to one of the footpads to study the magnetic properties of the regolith, and a vernier engine erosion experiment was conducted. The lander carried convex mirrors to provide views under the spacecraft.

The target sites considered for Surveyor 5 were the same as for Surveyor 4. They were 24E-1N, 4E-5S and 1W-1N (see Table 15, Figure 36). 24E-1N in Mare Tranquillitatis was selected (Minutes of the 14 June 1967 meeting of the Surveyor/Orbiter Utilization Committee). This would become the Apollo 11 landing site.

Surveyor 5 was launched from Pad 36B at Cape Kennedy on an Atlas-Centaur at 07:57 UT on 8 September 1967. After a short period in parking orbit the Centaur re-ignited to send Surveyor 5 to the Moon. This initial trajectory was very precise, the uncorrected impact point (2.32° N, 23.74° E) being only 46 km from the target point at 0.83° N, 24.00° E (Figure 91A). After Surveyor 5 made a small midcourse correction, a helium regulator leak compromised the vernier (landing) propulsion system. Several vernier firings and five additional midcourse trajectory adjustments were made to create a new flight plan which could overcome the vernier problem. The first midcourse correction had been intended to adjust the target point to 0.916° N, 24.083° E. Surveyor 5 landed safely at 00:47 UT on 11 September in southern Mare Tranquillitatis (Figure 139), among clusters of secondary craters roughly 15 km west of Sabine D (Figures 91A, 92). The spacecraft touched down on the inner slope of a 10 m diameter crater angled at about 20° (Figure 91B).

Figure 92A shows the initial landing ellipse suggested by tracking, and Figure 92B shows a later, more refined ellipse. The actual landing site is just outside this second ellipse on its north side, but if the ellipse was moved to match modern coordinates it would probably contain the landing site. Surveyor 5 landed just outside the area of high resolution Lunar Orbiter images covering this Apollo site and could not be identified in Apollo or Clementine images, so until LRO images became available in 2009 the exact location of the spacecraft was not known. The contemporary tracking solution was 1.41° N, 23.18° E, and the revised LRO location is 1.455° N, 23.194° E, (Robinson, 2010; Wagner *et al.*, 2017).

Despite its earlier problems the spacecraft functioned better than its predecessors, transmitting 18,006 high quality images during its first lunar day, ending on 24 September. 53 hours after landing the verniers were fired for 0.55 seconds to observe erosion effects on the regolith. Loose particles were moved, as was the alpha scattering instrument. At lunar noon the solar panel and main antenna were used to shade parts of the spacecraft when temperatures rose above safe operational levels, a result of the location inside a crater. Solar corona and earthshine images were taken after sunset.

On 15 October, after the long lunar night, Surveyor 5 resumed operation, returning 1048 additional pictures and 22 hours of additional alpha scattering data. The spacecraft survived an eclipse of the sun by Earth on 18 October. Transmissions were received until 1 November when the second night-time shutdown began. Communication attempts continued on the third and fourth lunar days, succeeding only on the fourth day, with final transmissions on 17 December. Images were received during the first, second and fourth lunar days (NASA 1967; JPL 1967; JPL 1969).

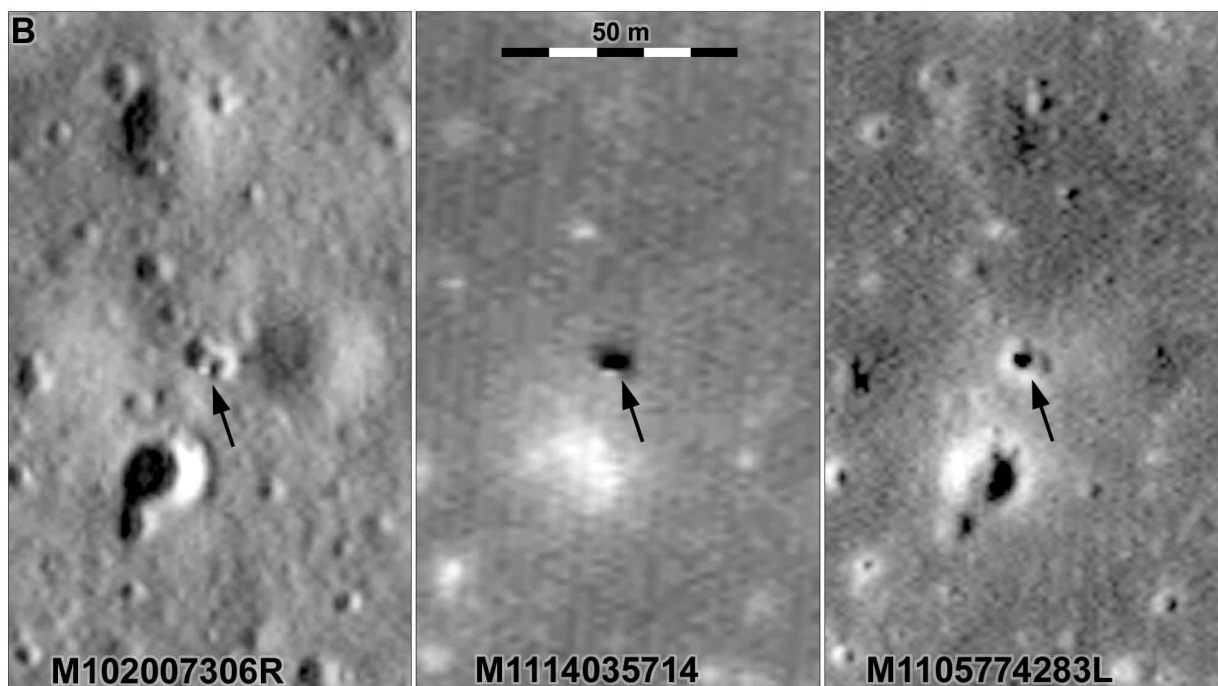
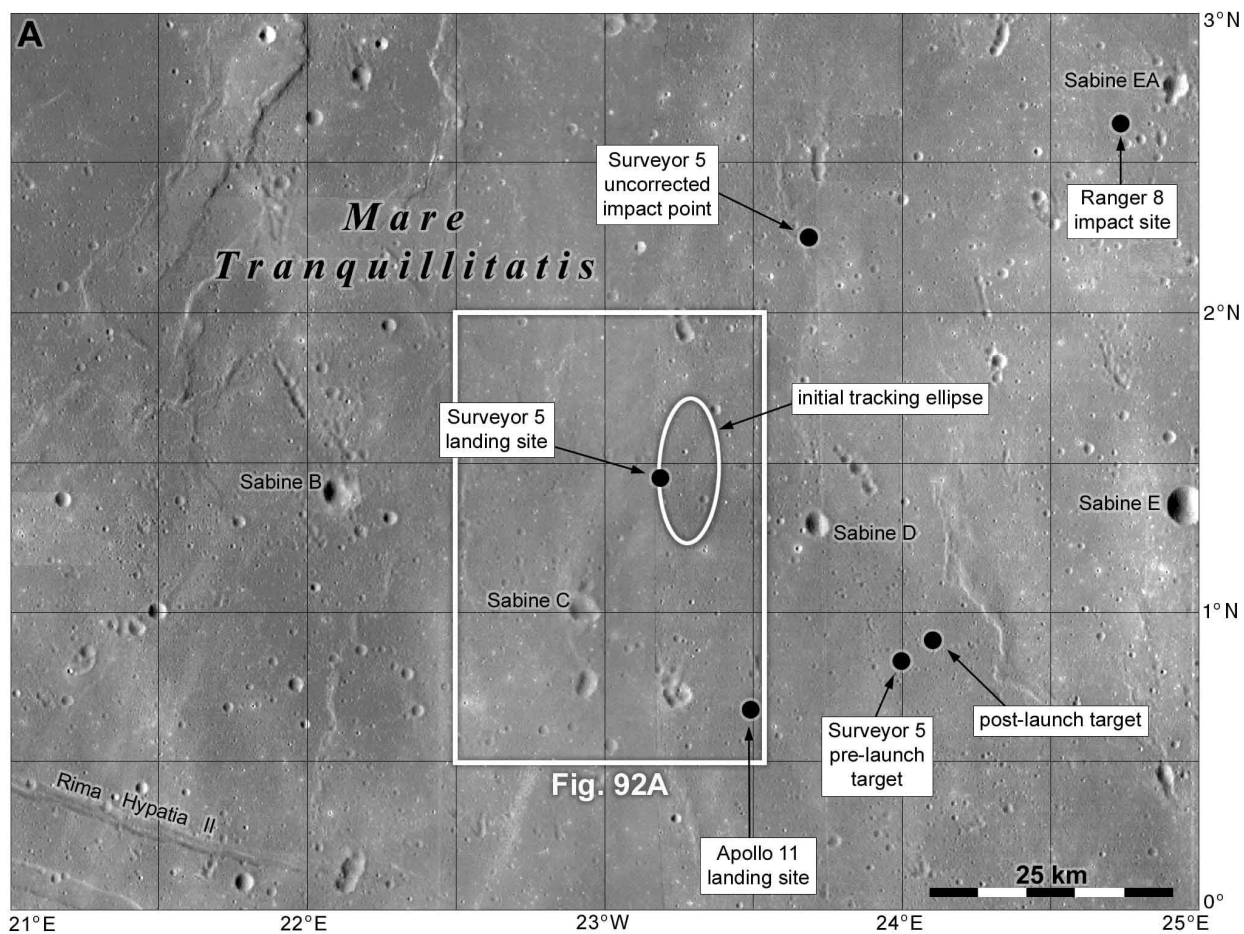


Figure 91. Surveyor 5 landing site. A: the region surrounding the landing site. B: Surveyor 5 (centre of each frame) viewed with three different lighting conditions in LROC images. The arrow indicates Surveyor 5.

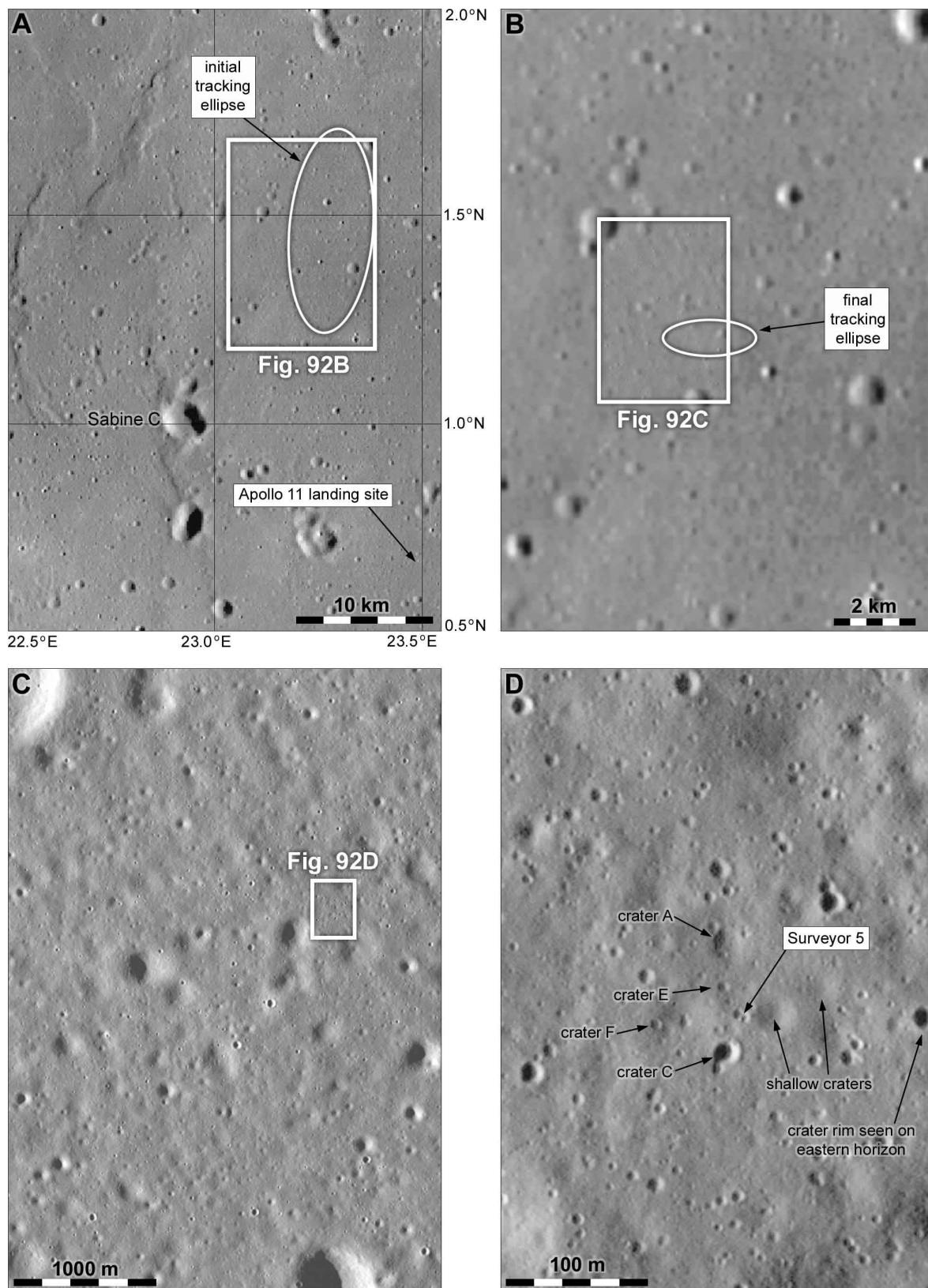
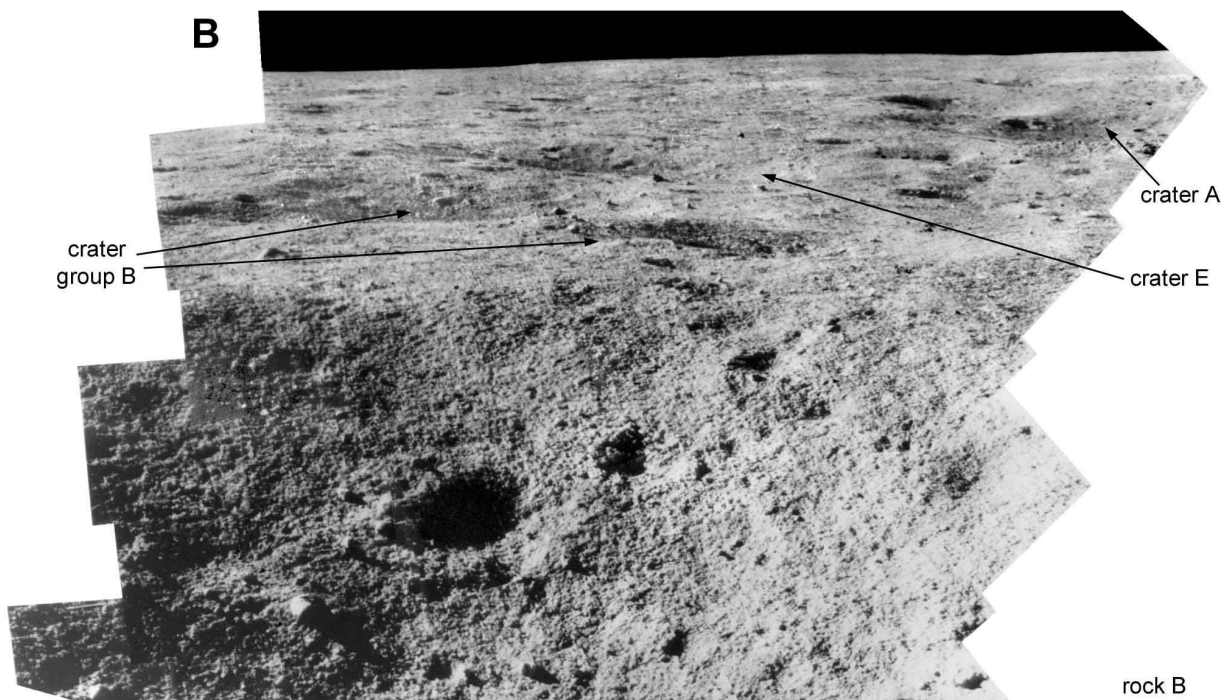
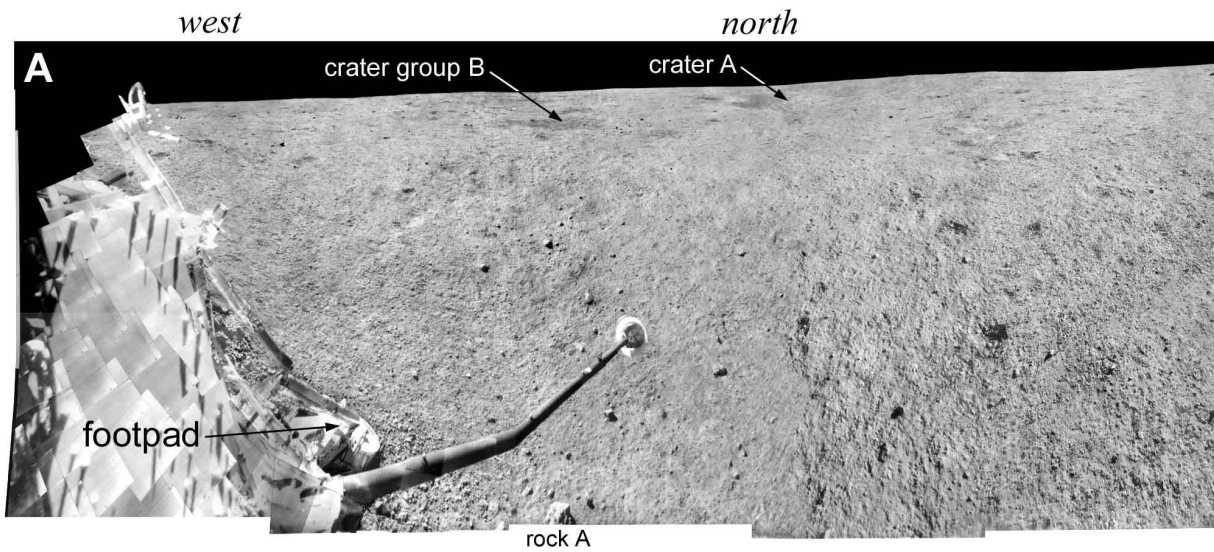


Figure 92. The Surveyor 5 landing site. A, B: the region seen in LROC wide angle mosaics. C, D: the site seen in LROC image M102007306R.



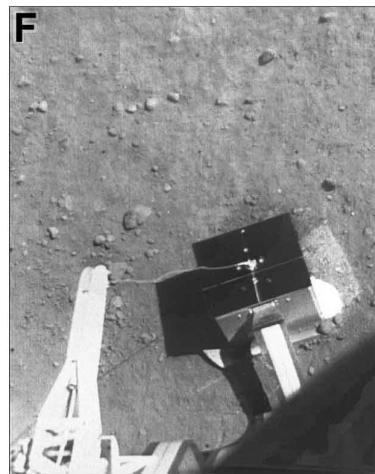
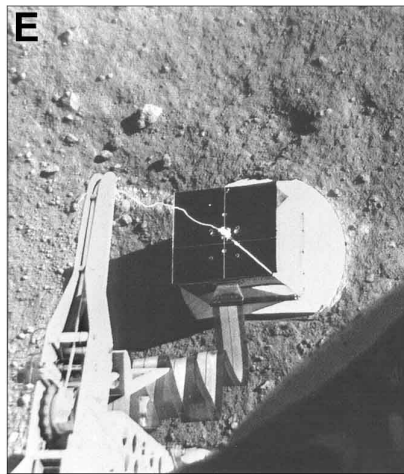
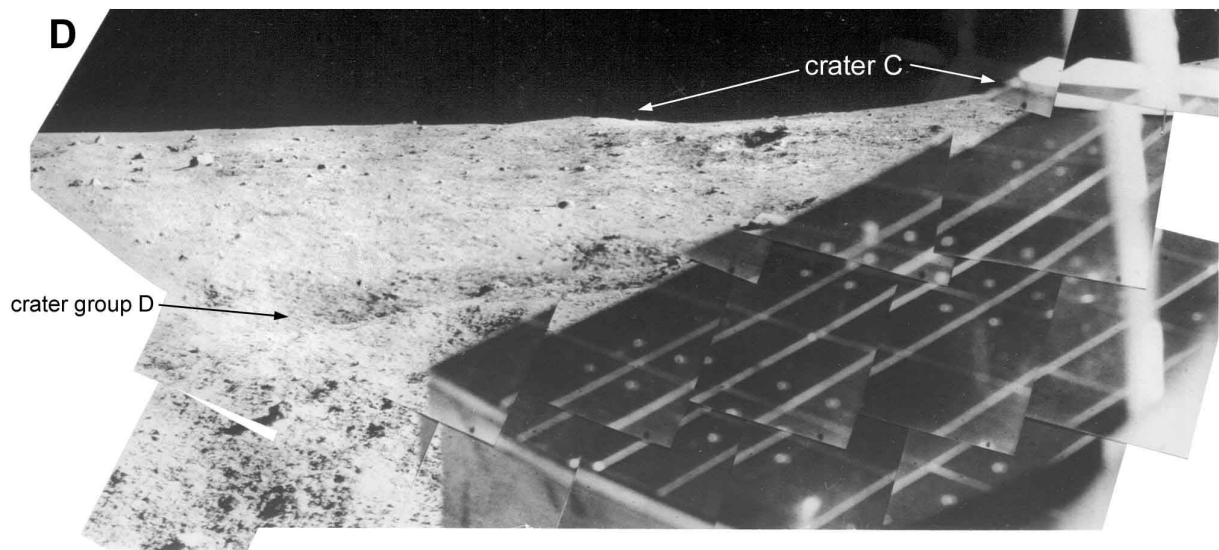
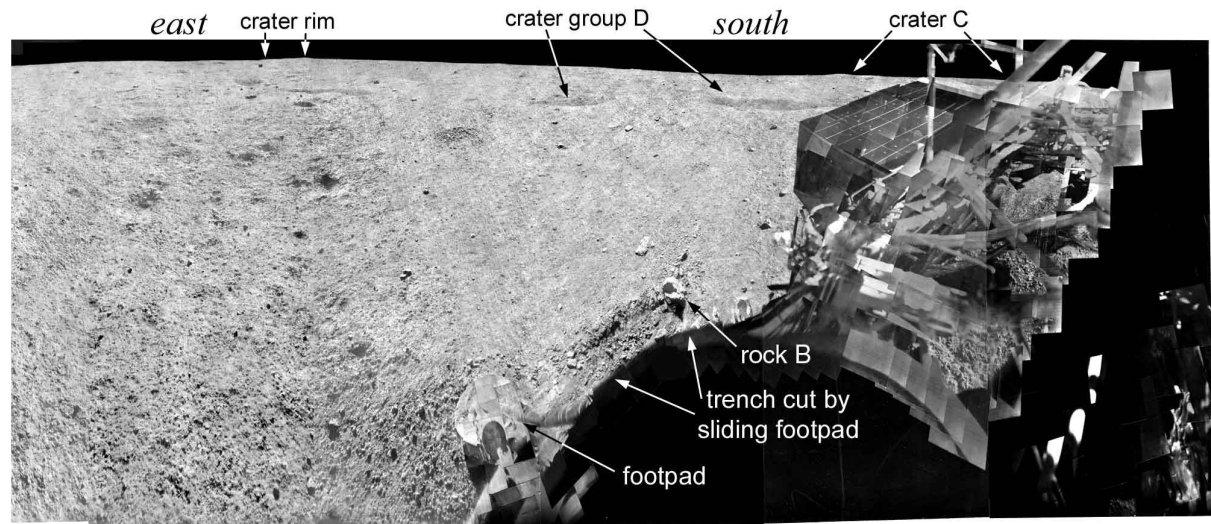


Figure 93 (both pages). Surveyor 5 images. A (both pages): full panorama, high sun angle. B: view to the north with a lower sun angle. C: trench cut by sliding footpad. D: view to the south. E, F: alpha-scattering instrument (black-topped box) before (E) and after (F) the vernier engine firing.

Figure 93A (across both pages) is a full panorama taken near local noon with very limited shadows to indicate relief. The rim of the crater Surveyor 5 landed in is invisible in this panorama. Figure 93B shows the horizon north of the landing site, with a lower sun elevation than the full panorama. The rim and inner slope of the Surveyor 5 crater are visible in the foreground. Figure 93C shows a trench cut by the footpad as the spacecraft slid down the wall of the crater it landed in. The trench is about 1 m long. Figure 93D is the view to the southern horizon, looking over the black electronics box. It shows the prominent rim of crater C, a few tens of meters from the landing site. Figures 93E and 93F are views of the alpha-scattering instrument (black-topped box) before and after the vernier engine firing. The instrument and many soil particles moved slightly, giving some indication of the effects of rocket firings on the regolith to help with future Apollo landing plans.

Figure 94A portrays the surroundings out to about 100 m from the spacecraft. A crater rim forms a small hill south of Surveyor (crater C). Feature positions in this map are not well controlled because of the oblique viewing and lack of orbital images at this resolution. Shallow craters east of the lander are not apparent in Figure 93 but can be seen filling with shadow in images with very low angle illumination.

Figure 94B shows the immediate surroundings of Surveyor 5. The spacecraft landed on the wall of a small crater and slid onto its floor, coming to rest on a slope of about 20°. Craters and rocks identified in the panoramas (Figure 93) are indicated in these maps to provide a link between the two. The floor of the crater is mapped at larger scale in Figure 95A. Sliding during the landing disturbed the regolith along the wall of the crater, as shown. The alpha-scattering instrument measured the composition of the disturbed material. The two visible footpads cut trenches in the regolith, and the third probably did as well, but this could not be observed. Faint lineations, shown here as shallow grooves, were seen on the crater floor in front of the spacecraft. Some geologists thought these reflected underlying structures, but the consensus became that they were ephemeral lighting effects. Spurious lineations like these are commonly seen on rough surfaces with very oblique illumination.

Jaffe *et al.* (1968) summarized the results of the Surveyor 5 mission, describing the crater in which the spacecraft landed as part of a chain of rimless craters which might have been formed by drainage of regolith into a subsurface void along a fracture. LRO images do not support this interpretation.

The Surveyor 5 retro-rocket impact has not been unambiguously located. Several dark spots are visible in high sun images, and in a composite of morning and evening illumination images which cancel shadows (Figure 96A). One of them is a 4 m diameter crater resembling the Surveyor 3 retro-rocket crater, and is most likely to be the impact site (Figures 96B, 96C). A dark spot south of the lander is another candidate (Figure 96D) but does not appear to be a crater. Stooke (2016a) identified only the southern spot in the LPSC abstract, noting possible bounce marks near it. Stooke (2016b) identified both of these features, favouring the crater site, in the poster at the same conference. The two sites are 350 m north and 250 m south of the lander. In 2025 the LROC team's ACT Quickmap added the southern site to its layer of anthropogenic features.

Jaffe, L. D., Batterson, S. A., Brown, W. E. *et al.*, 1968. Principal science results from Surveyor 5. *Journal of Geophysical Research*, v. 73, pp. 7165-7167.

JPL 1967. *Surveyor V mission report*, JPL Tech. Rep. 32-1246. Pasadena: Jet Propulsion Laboratory.

NASA, 1967. *Surveyor V: a preliminary report*. NASA SP-163. Washington, D. C.: National Aeronautics and Space Administration.

Robinson, M., 2010. Surveyor 5: a hole-in-one. Blog post, 21 March 2010. <https://www.lroc.asu.edu/images/14>

Stooke, P.J., 2016. Surveyor Retro-Rockets in LROC Images. Presented at the 47th Lunar and Planetary Science Conference, The Woodlands, Texas, 21-25 March 2016. Abstract no. 1025.

<https://www.hou.usra.edu/meetings/lpsc2016/pdf/1025.pdf>

Stooke, P.J., 2016. Surveyor Retro-Rockets in LROC Images. Presented at the 47th Lunar and Planetary Science Conference, The Woodlands, Texas, 21-25 March 2016. Poster no. 1025.

<https://www.hou.usra.edu/meetings/lpsc2016/eposter/1025.pdf>

Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp.92-103. <http://dx.doi.org/10.1016/j.icarus.2016.05.011>

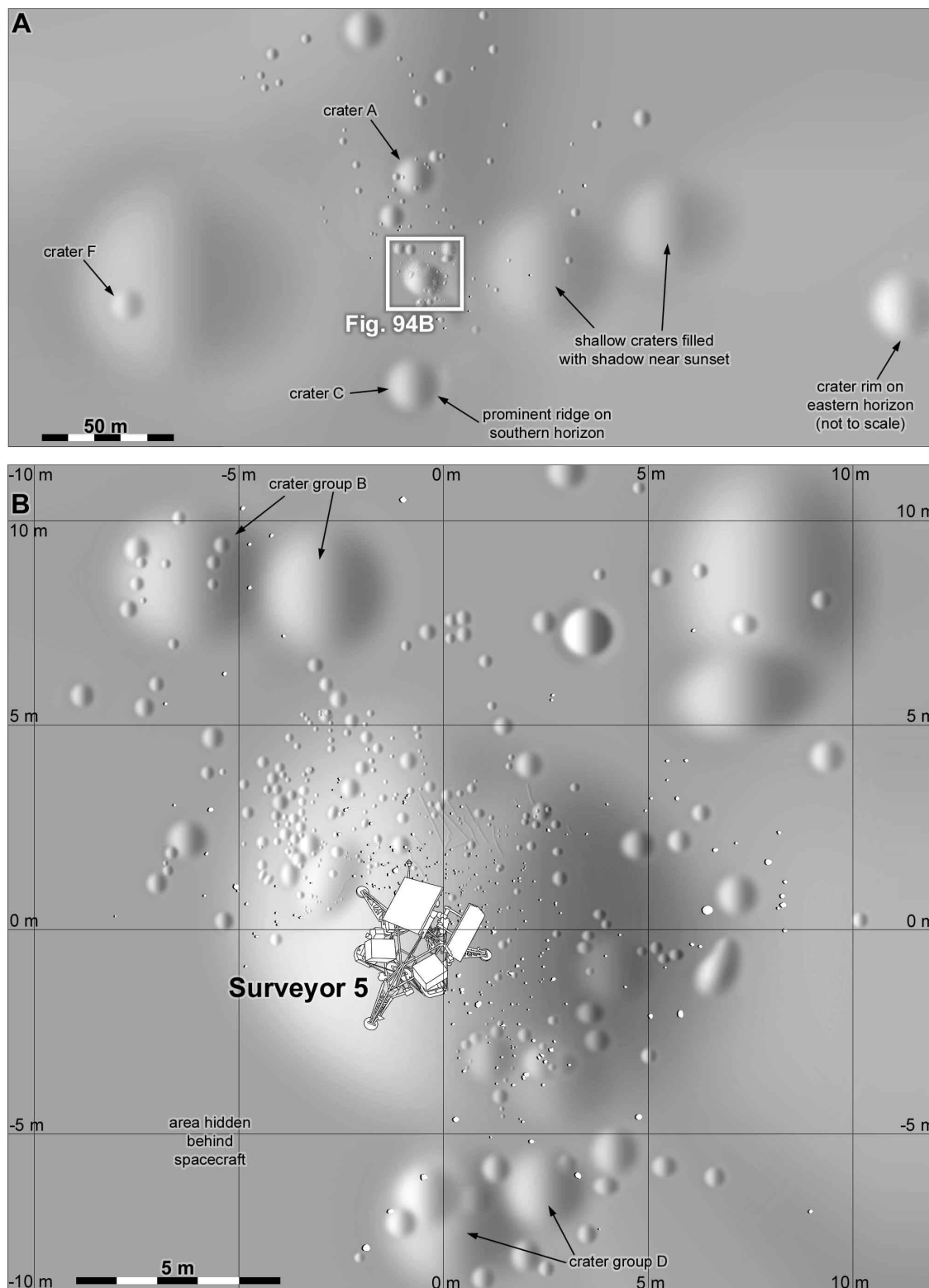


Figure 94. Plans of the Surveyor 5 landing area made from panoramic images. A: the area surrounding the landing site, modified from Figure 3-4 of NASA (1967) with the addition of features seen in low sun images and on the horizon. Relief drawing by P. Stooke. B: The surface near the lander, adapted from JPL (1967) by P. Stooke, with additions from NASA (1967).

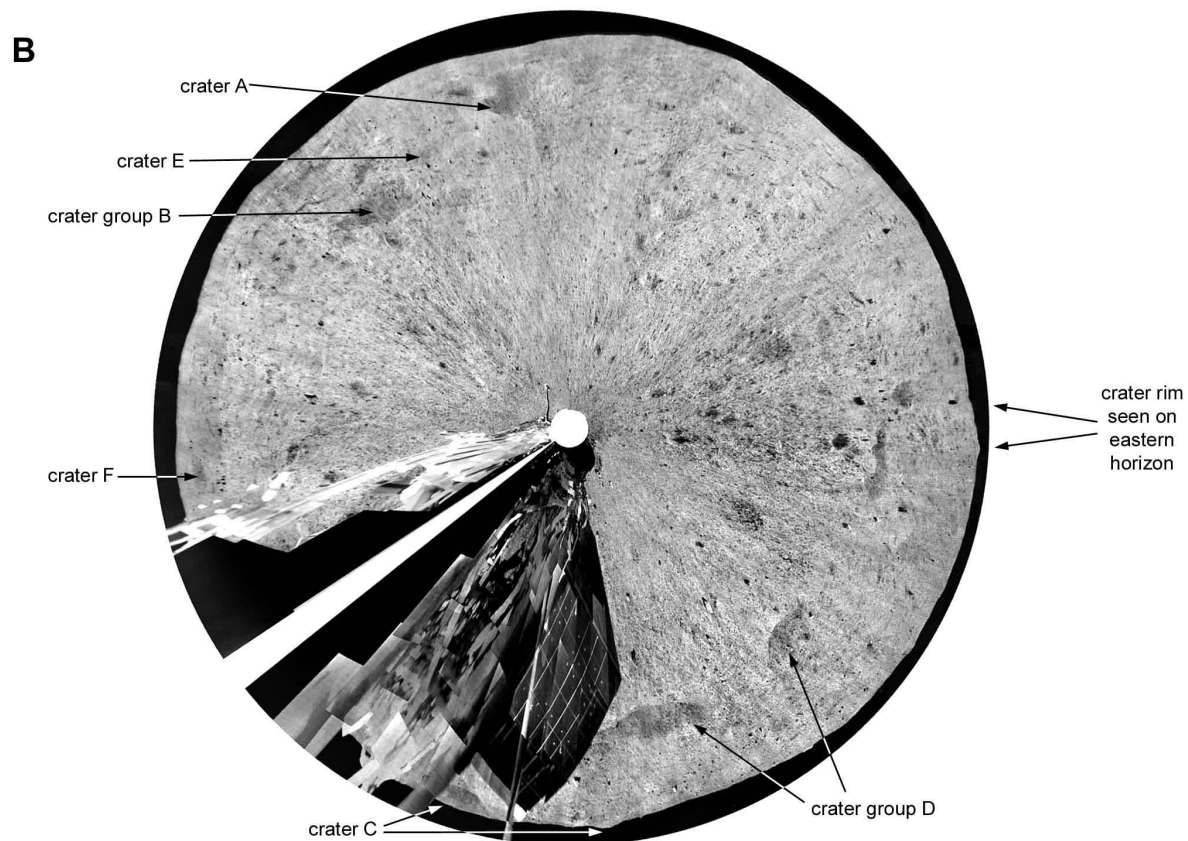
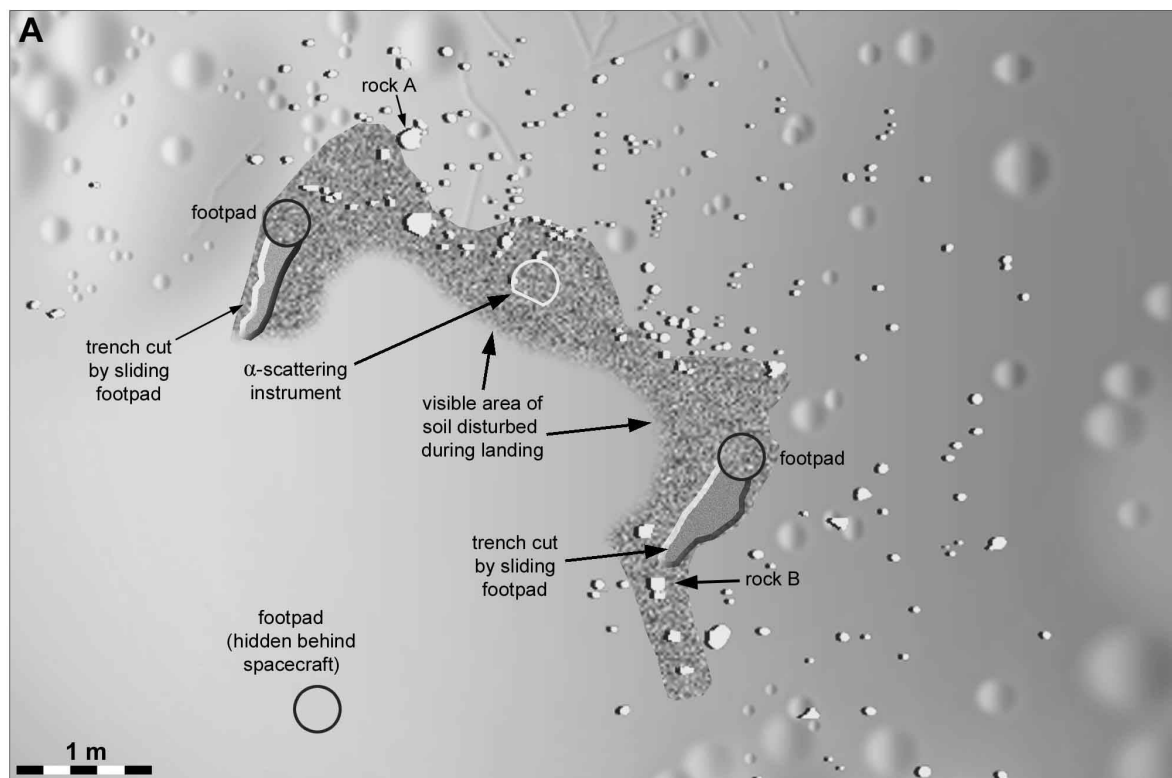


Figure 95. The Surveyor 5 landing site. A: Immediate environs of the lander. B: reprojected panorama (Figure 93A), with craters identified for comparison with Figures 92D, 93 and 94.

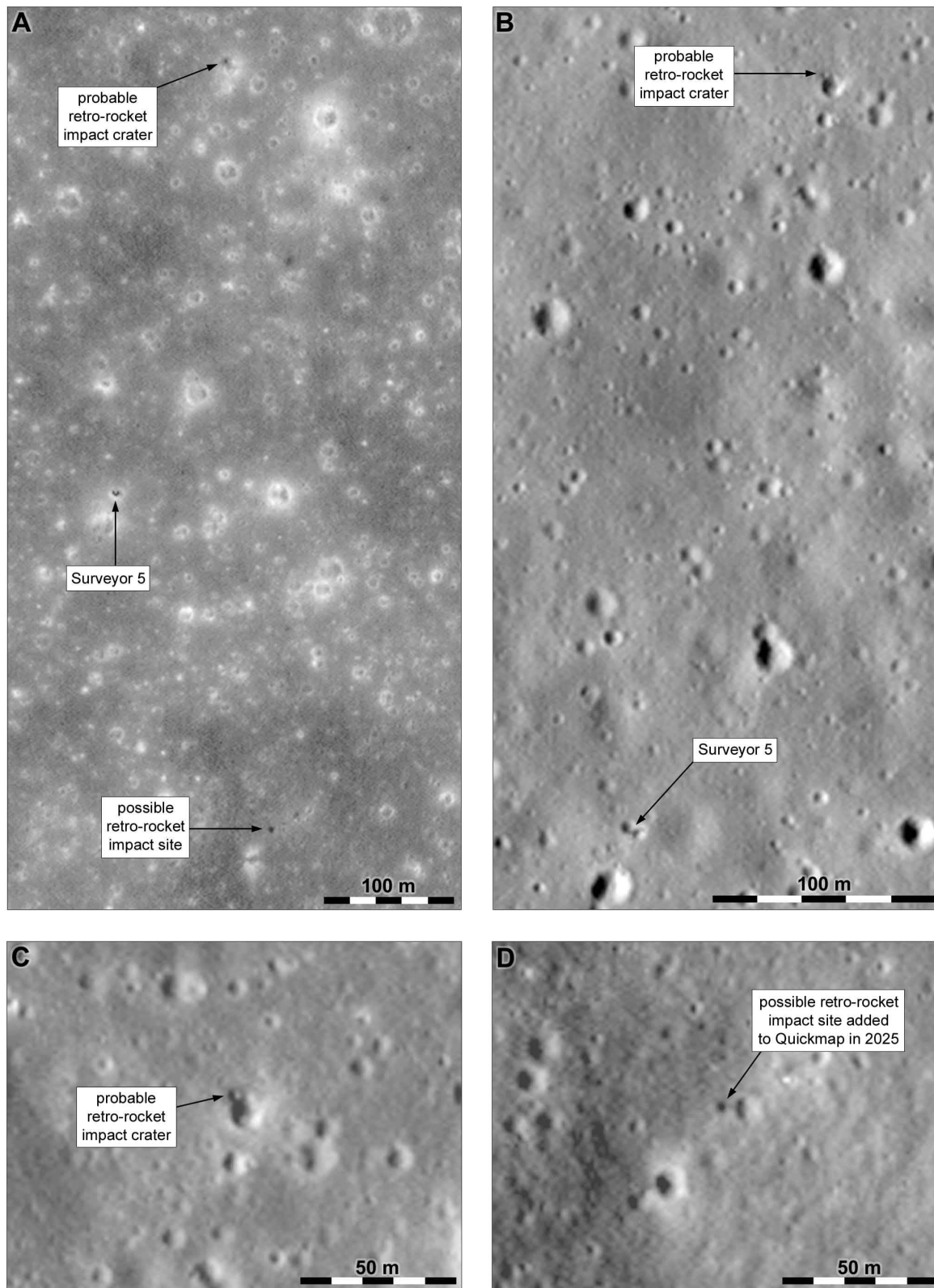


Figure 96. The Surveyor 5 retro-rocket. A: LROC images M106726943L and M1105774283L, merged to cancel shadows. Several dark spots are revealed. B: LROC image M181016020R showing Surveyor 5 and the probable retro-rocket impact crater. C, D: enlargements of two features in LROC image M181016020R.



27 September 1967: Soyuz lunar test launch

The Soviet Union made its first attempt at a circumlunar flight with the new Soyuz spacecraft, without a crew, on 27 September 1967. The Soyuz capsule was being developed for the human lunar landing program. The launch vehicle crashed 65 km from the launch site after a first stage engine malfunction, but the escape system successfully saved the spacecraft from destruction. It was recovered later.

There were two precursors: Cosmos 154 on 8 April 1967 was a prototype of the piloted circumlunar spacecraft. It reached earth orbit but the upper stage failed to fire because its ullage rockets, used to force propellants to the bottom of their tanks before an engine firing in weightlessness, were discarded prematurely. The spacecraft was a lunar Soyuz but was designated Cosmos 154 after the launch to conceal its purpose. It burned up two days later when its low orbit decayed. Cosmos 159 on 17 May 1967 was a high Earth orbit test of tracking and communications for the Soviet piloted lunar program. It used a radio-equipped version of the now abandoned Luna 9-style lander.



22 November 1967: Soyuz lunar test launch

This was the Soviet Union's second attempted circumlunar flight. The Soyuz was again flown without a crew. Four seconds after the second stage ignited the Proton launcher lost attitude control. The escape system shut down the engines and pulled the spacecraft away from the booster. The launcher crashed 300 km from the pad and the Soyuz was recovered safely. It was clear that the launch system would not be ready to carry cosmonauts for some time.



07 November 1967: Surveyor 6

Surveyor 6 was almost identical to Surveyor 5, including an alpha-particle scattering instrument which measured the elemental composition of the regolith. A bar magnet was attached to one footpad to examine the magnetic properties of the regolith. Surveyor 6 was launched at 07:39 UT from pad 36B at Cape Canaveral, and after a short time in a partial parking orbit the Centaur upper stage ignited to send Surveyor 6 to the Moon. The discarded Centaur eventually passed 28,000 km from the Moon and entered solar orbit. The spacecraft landed in Sinus Medii on 10 November at 01:01 UT (Figures 97, 98).

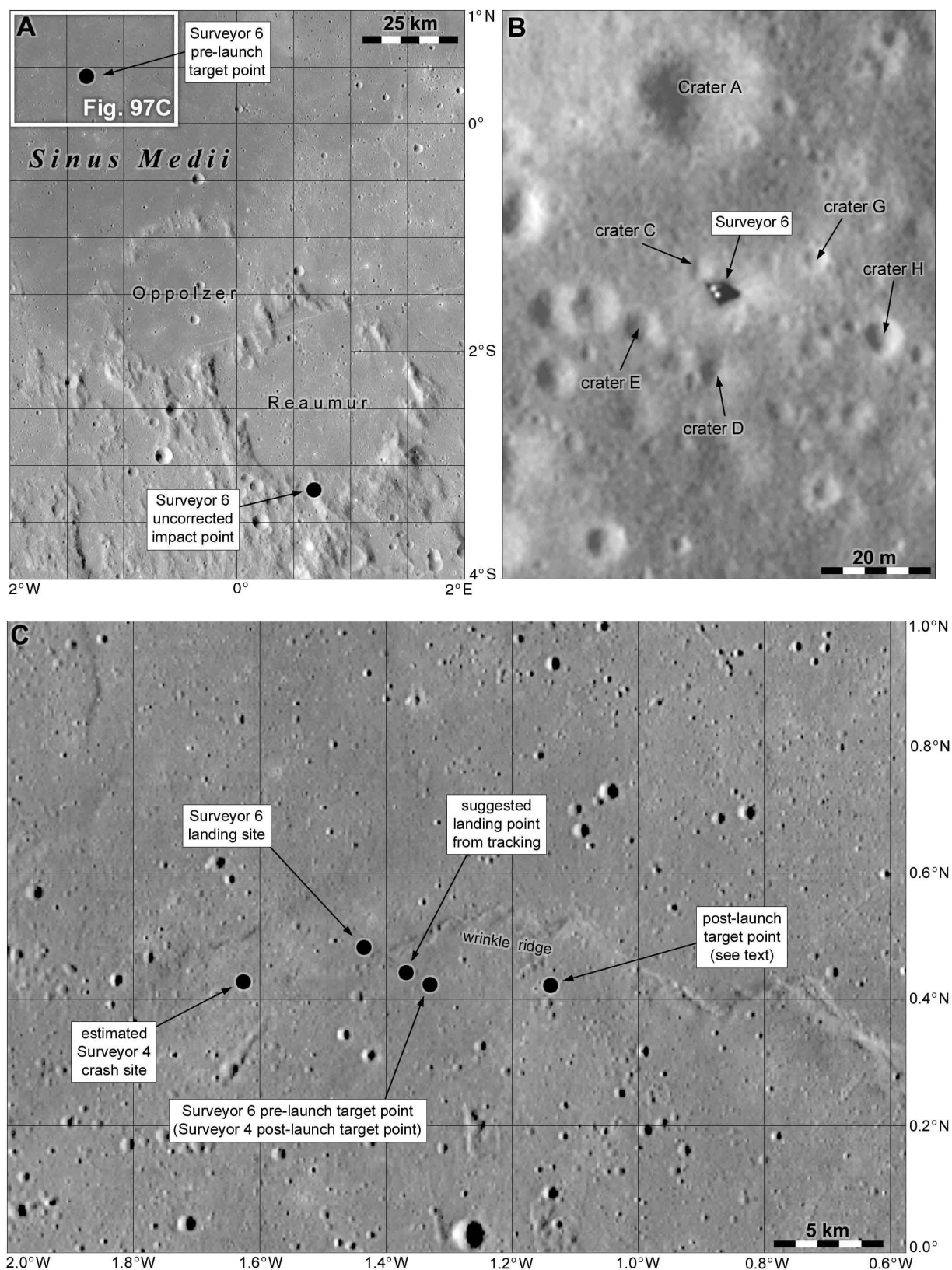


Figure 97. Surveyor 6 landing site. A: the landing region in Sinus Medii. B: Surveyor 6 on the surface in LROC image M152885739L. C: The target points and landing site. A and C are LROC wide angle mosaics.

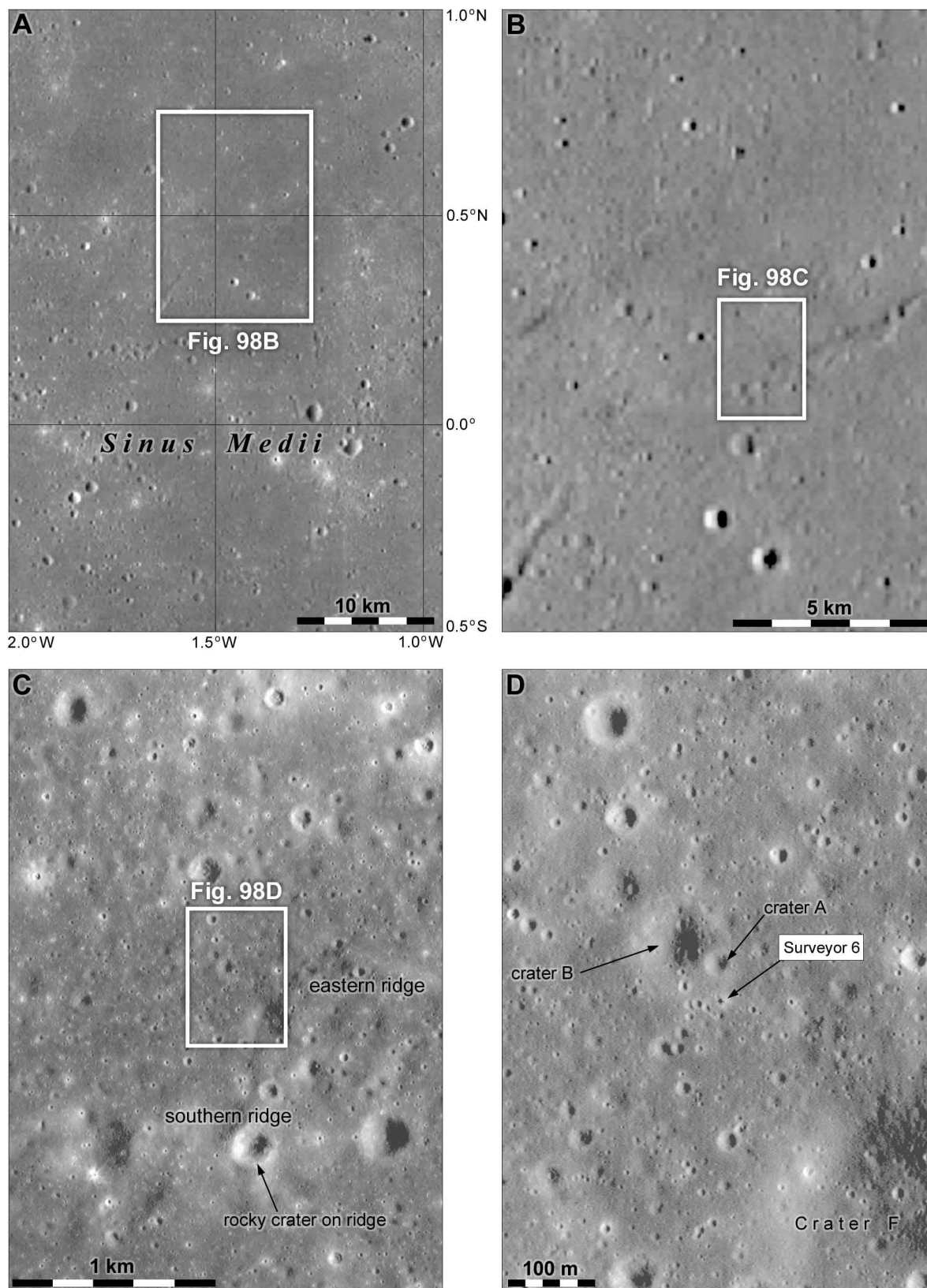


Figure 98. The Surveyor 6 landing site. A, B: LROC wide angle mosaics. C, D: parts of LROC image M190608838L.

Wilhelms (1993) describes several science targets considered for Surveyor 6, including Fra Mauro, Alphonsus, Copernicus and the Marius Hills, but Apollo's requirement for a landing in Sinus Medii was the decisive factor. The impact point, if no correction or braking had occurred, would have been at 3.21° S, 0.66° E, about 125 km from the target (Figure 97A). The pre-launch target was 0.42° N, 1.33° W in Sinus Medii, at one of the preferred Apollo sites, close to the Surveyor 2 and 4 targets and identical to the Surveyor 4 post-launch adjusted target (Figure 97C). The midcourse trajectory correction 18.6 hours after launch adjusted the target to 0.417° N, 1.133° W (*sic* in project documents, but possibly a consistent misprint for 1.333° W), and subsequent tracking suggested a landing at 0.437° N, 1.370° W. The landing site was soon located on Lunar Orbiter images at 0.470° N, 1.480° W, which is 0.474° N, 1.428° W in LRO coordinates (Wagner *et al.*, 2017).

The 299 kg spacecraft functioned almost perfectly on the surface, returning 29,952 images and 30.5 hours of alpha-scattering data. It fired its attitude control gas jets and observed their effects on the regolith. It also performed a successful 2.5 second vernier engine burn, initiating the first launch from the lunar surface, in which it hopped about 4 m high and 2.5 m to the west before landing safely. It photographed the resulting erosion of the surface and its original footpad imprints to illustrate the effects of rocket exhaust on the regolith. After the hop the alpha-scattering instrument was left lying on its side and could not gather further data on the regolith, but it was operated for another 13 hours to collect data for possible cosmic proton studies. The spacecraft shut down after taking earthshine and solar corona images a few hours after sunset on 24 November. It was contacted again on 14 December, but no useful data could be collected during the three hours of limited activity before operations ceased (NASA 1968a; JPL 1968; Jaffe, 1968)

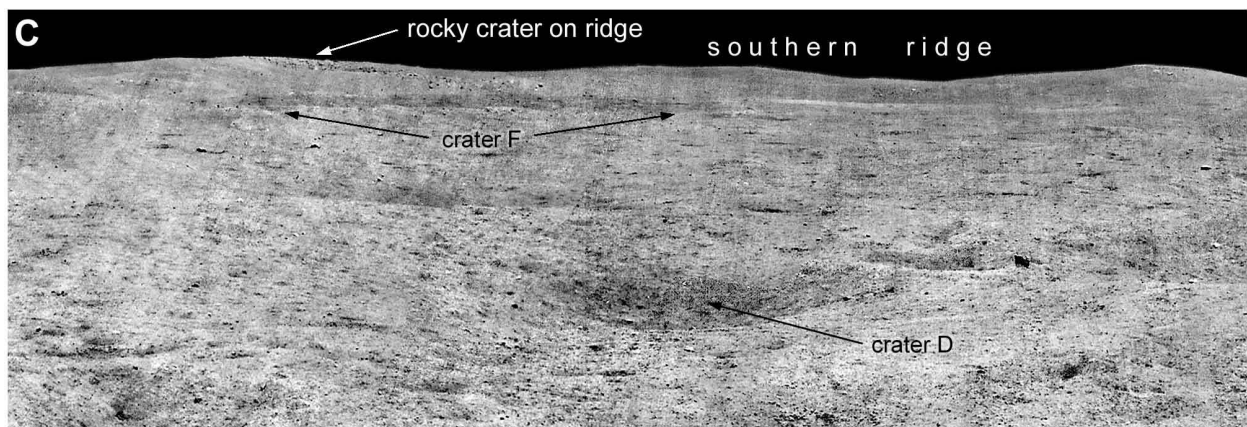
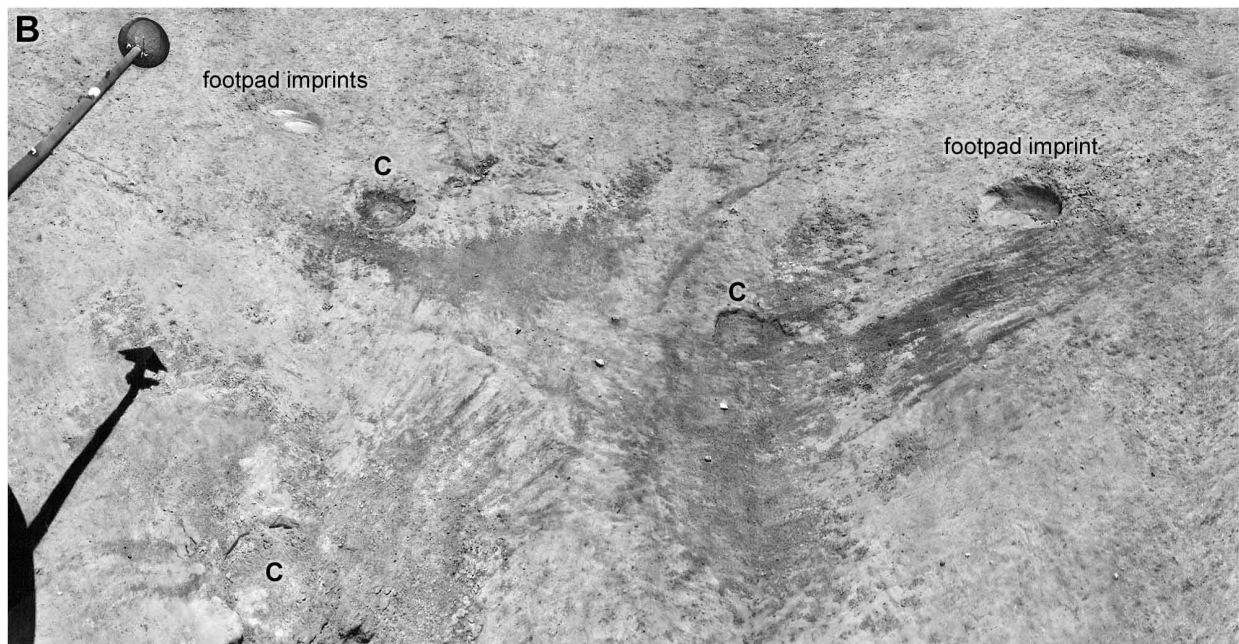
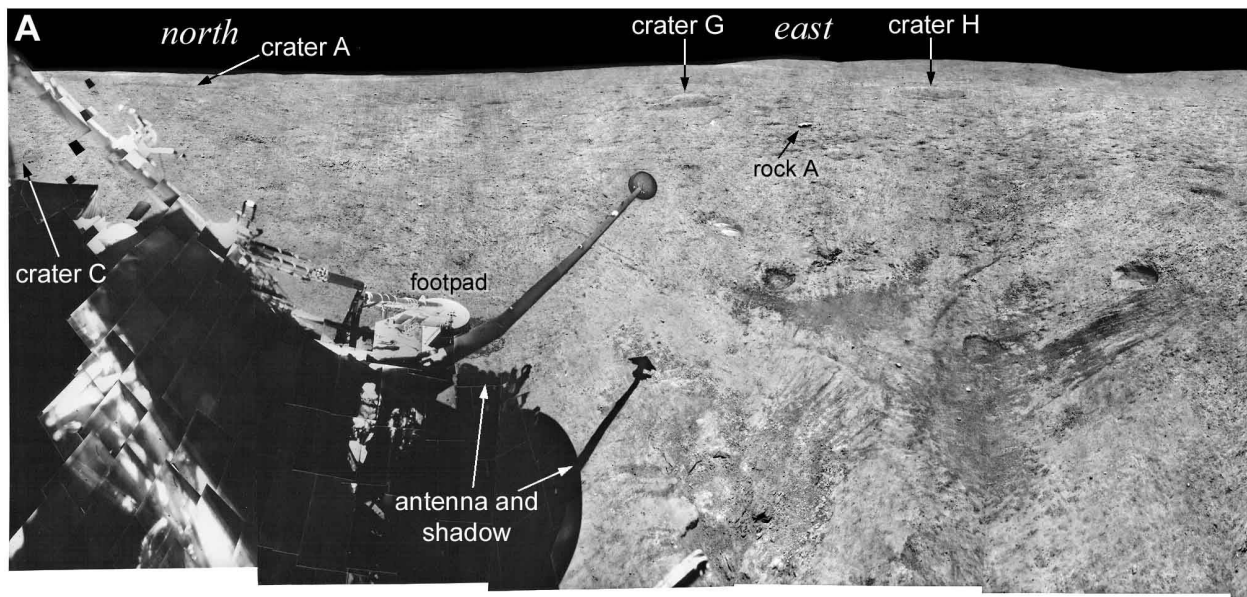
Surveyor 6 landed just north of and in sight of a mare ridge, sometimes called a wrinkle ridge. These irregular ridges are found on many mare surfaces across the Moon and are interpreted as the surface expressions of thrust faults in the underlying lava caused by compressional forces. The weight of the thick mass of lava causes the surface to subside, creating compression in the surface. Prior to Apollo some ridges were also interpreted as volcanic extrusions. This was the only mare ridge seen by a Surveyor spacecraft.

Figure 99A (across both pages) is a full panorama of the landing site, taken after the spacecraft's Vernier thruster firing and hop. The high sun makes relief difficult to discern. Streaks in the foreground at left were produced by the Vernier exhaust. These are seen more clearly in Figure 99B, an enlarged view of the footpad imprints from the first landing, and vernier exhaust marks. Three marks left by the 'crushable block' shock absorbers are indicated. A third footpad imprint from the first landing would be underneath the post-hop spacecraft position and is not visible.

Figure 99C shows the southern horizon with a prominent mare ridge near the landing site. A rocky-rimmed crater on the ridge is identified in Figure 98, and other craters and a rock visible in the panorama are identified in Figures 97B and 98.

Figure 99D is a mosaic of images showing the southern horizon near sunset. The rough nature of the ground would probably have excluded this specific location from consideration as an Apollo landing site. The Apollo site planned for this area was at the original Surveyor 6 target on the south side of the ridge (Figure 97C).

Figure 100 is a plan of the landing site drawn from Surveyor 6 images, modified by P. Stooke from Figure III-24 of JPL (1969). The visible footprints mark the initial landing site. After the vernier engine firing the spacecraft hopped about 2.5 m west to its final location, shown by the drawing of Surveyor 6, which has the correct size and orientation. Figure 101A shows the initial landing area in more detail. Two landing footprints are labeled, and the third lies under the final position of the spacecraft. Three points labeled C are surface imprints made by the crushable blocks under the upper leg joints. The map also indicates the location of the alpha-scattering instrument during its analysis of the surface before the hop. The same area is shown in Figure 101B as a reprojected version of the panorama (Figure 99B), revealing the marks left by the Vernier firing. The full reprojected panorama is shown in Figure 101C, with features labelled for comparison with Figures 97, 98, 99 and 100.



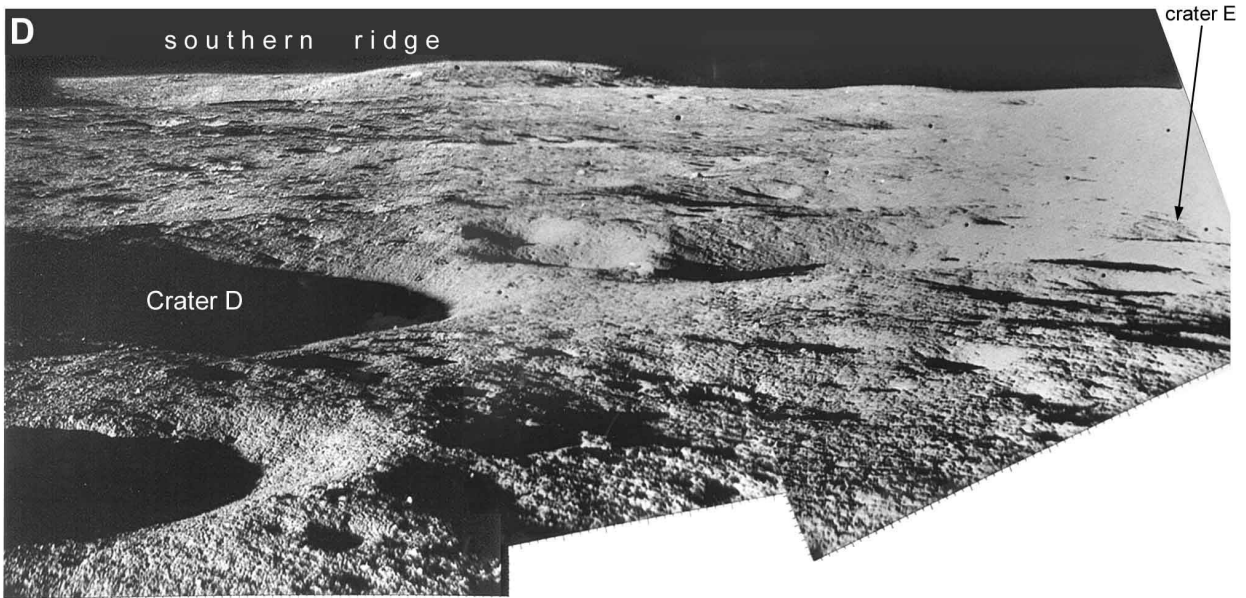
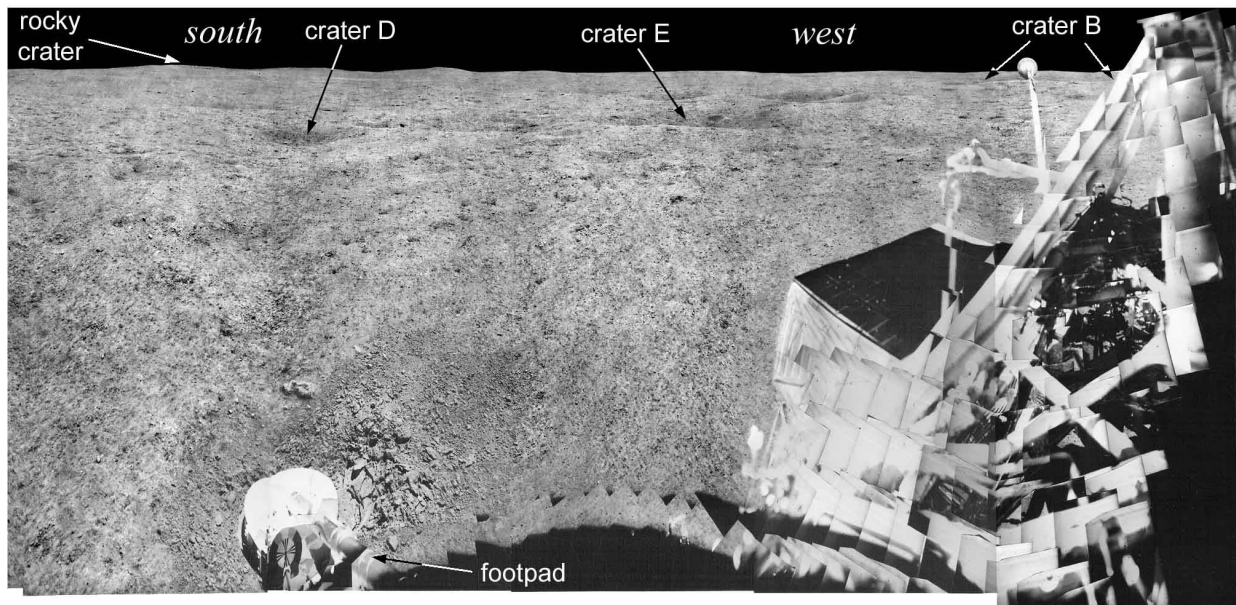


Figure 99 (both pages). Surveyor 6 images. A (both pages): full panorama. B: enlarged view of the Vernier thruster exhaust markings and spacecraft imprints. The 'C' labels indicate three circular marks left by the 'crushable block' shock absorbers. C: view to the southeast showing craters and the nearby wrinkle ridge. D: view to the south with a low sun angle to highlight relief.

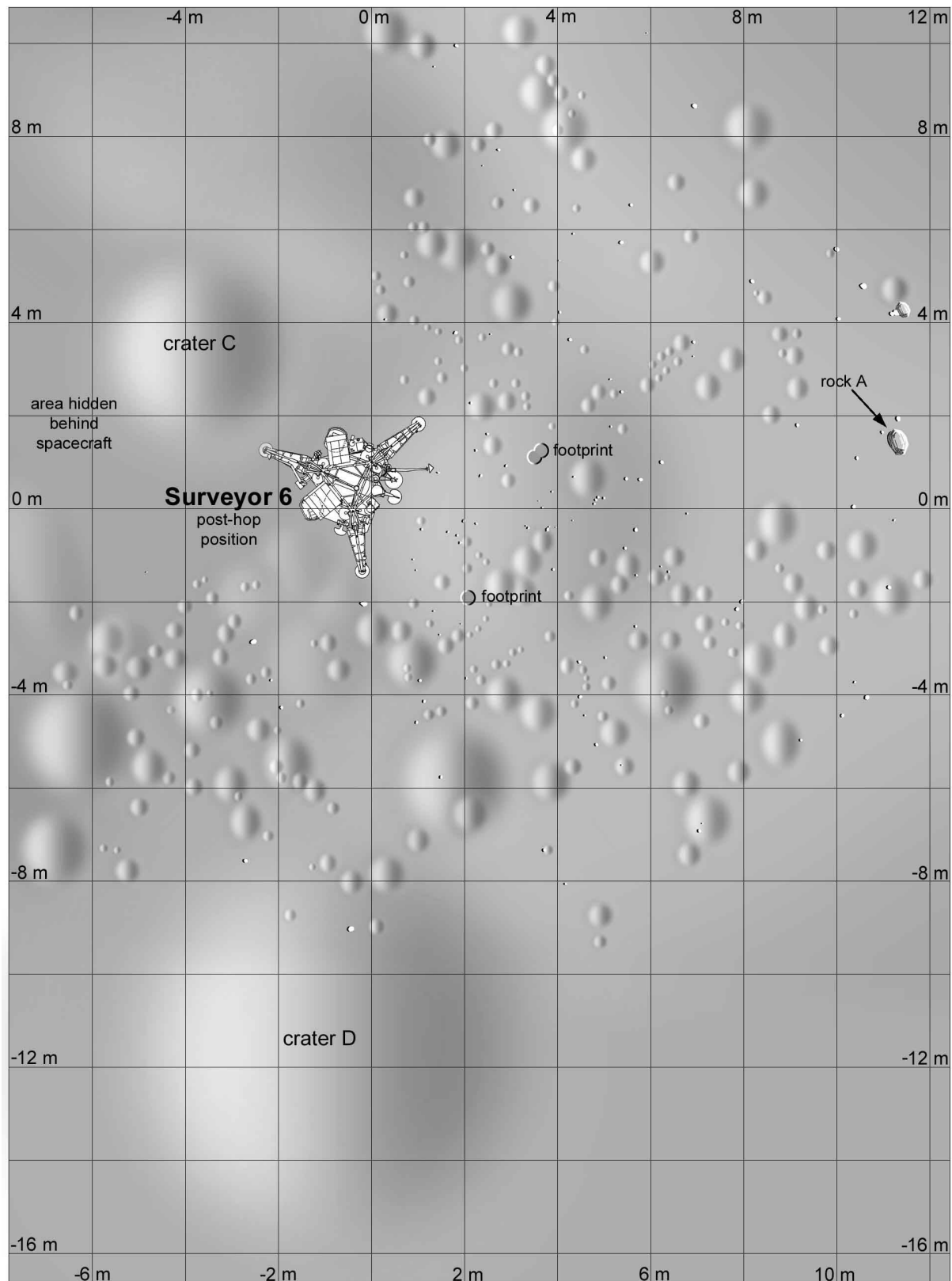


Figure 100. The Surveyor 6 landing site. A map derived from JPL (1969), shaded relief drawing by P. Stooke.

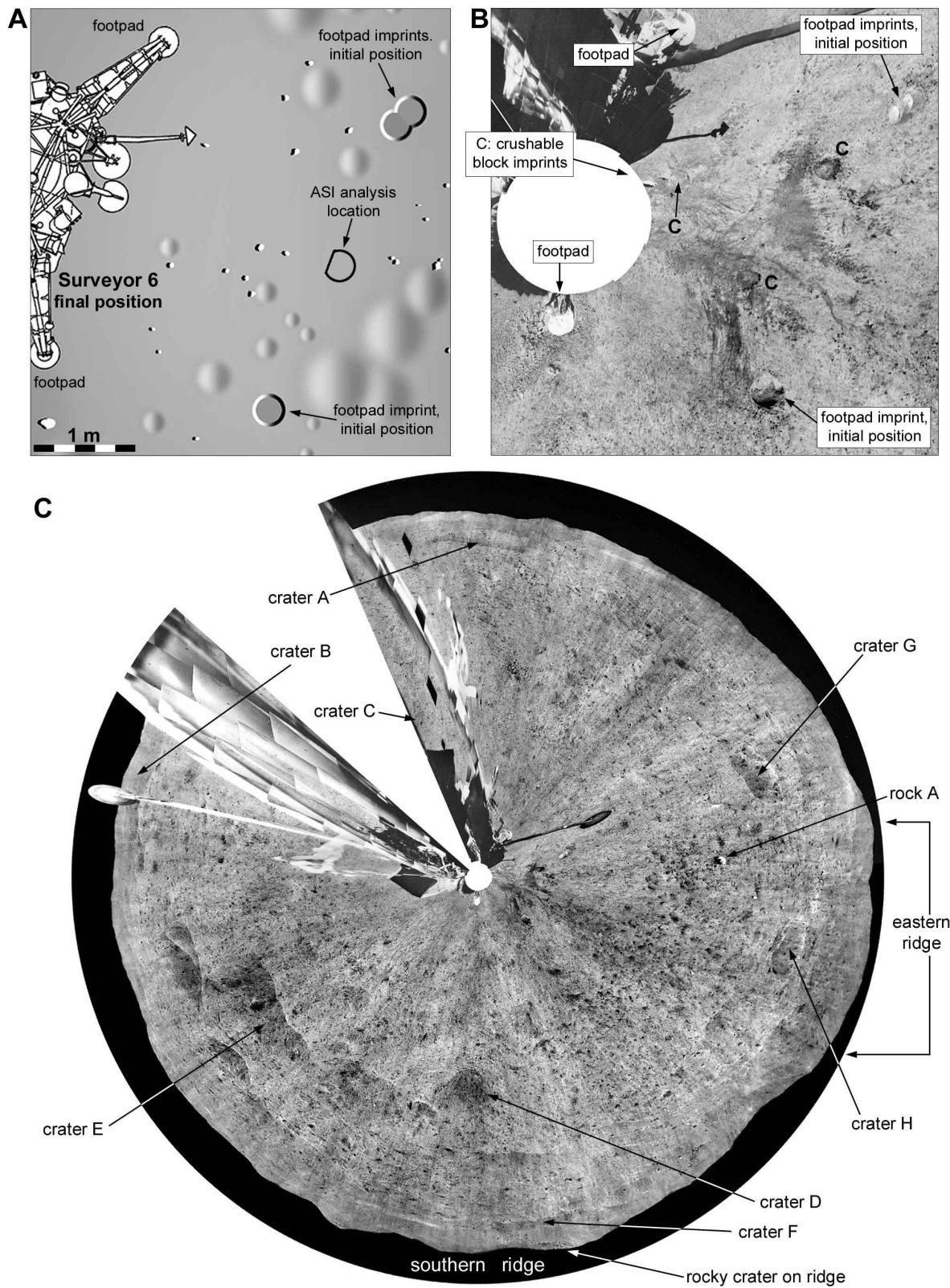


Figure 101. The Surveyor 6 landing site. A: enlargement of part of Figure 100 showing the footpad imprints and ASI location with the final position of the lander. B: reprojected panoramic image showing the first landing imprints and the exhaust effects of the Vernier firing. C: reprojected version of the full panorama (Figure 99A).

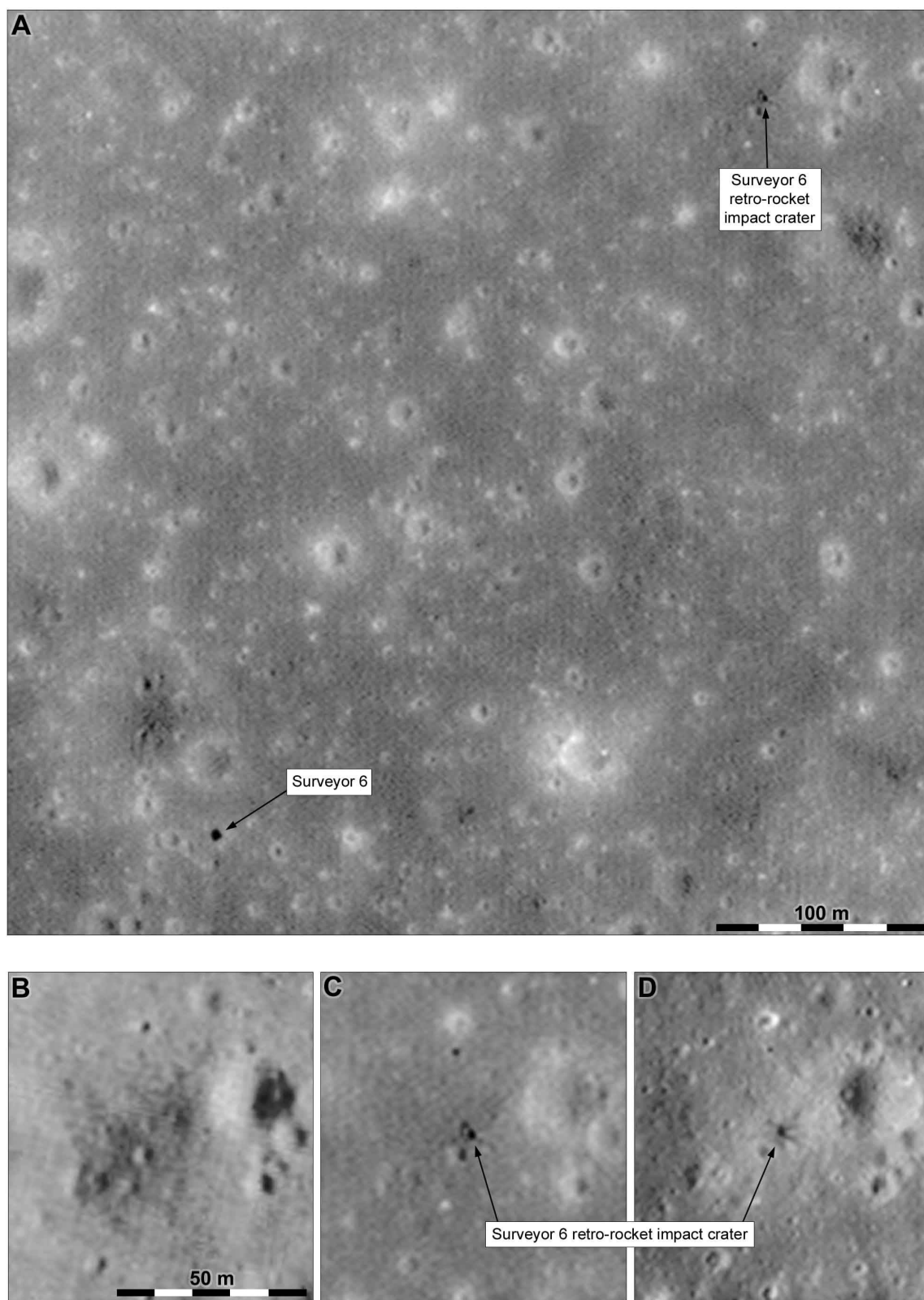


Figure 102. The Surveyor 6 retro-rocket impact. A: LROC image M188249922R showing Surveyor 6 and its retro-rocket impact. B: Lunar Orbiter 2 image II-121-H3, taken before the impact. C: enlargement of A. D: LROC image M152885739L.

The Surveyor 6 retro-rocket struck the surface about 400 m northeast of the lander (Figure 102A). Two dark markings are visible in high sun LRO images of this site, but a comparison with Lunar Orbiter 2 image II-121-H3 shows that one existed before the landing of Surveyor 6 (Figure 102B). The other one is a new feature (Figures 102C, D) made by the retro-rocket impact (Stooke, 2016).

Jaffe, L.D., 1968. Surveyor 6 lunar mission. *Journal of Geophysical Research*, v. 73, no. 16, pp.5297-5300.

<https://doi.org/10.1029/JB073i016p05297>

JPL 1968. *Surveyor VI mission report*, JPL Tech. Rep. 32-1262. Pasadena: Jet Propulsion Laboratory.

JPL, 1969. *Surveyor project final report*, JPL Tech. Rep. 32-1265, 1969. Pasadena: Jet Propulsion Laboratory.

NASA, 1968a. *Surveyor 6: a preliminary report*. NASA SP-166. Washington, D. C.: National Aeronautics and Space Administration.

Stooke, P.J., 2016. Surveyor Retro-Rockets in LROC Images. Presented at the 47th Lunar and Planetary Science Conference, The Woodlands, Texas, 21-25 March 2016. Abstract no. 1025.

Wagner, R.V., Nelson, D.M., Plescia, J.B. *et al.*, 2017. Coordinates of anthropogenic features on the Moon. *Icarus*, v. 283, pp.92-103. <http://dx.doi.org/10.1016/j.icarus.2016.05.011>



1967: Later Apollo Site Planning

As Lunar Orbiter 5 images became available, MSC staff in Houston began searching for suitable landing sites for later Apollo flights. By November they had analyzed 17 Orbiter 5 sites, identifying points of specific scientific interest (white circles in Figures 103 and 104) and possible landing sites near them (black circles, whose radius of 1 km provides scale for the images). A few areas had no obvious landing sites at this stage of the analysis, and some larger elliptical landing sites are also shown. Sixteen of these sites were illustrated in an MSC report circulated to GLEP Site Selection subgroup members for a meeting in Washington DC on 8-9 December. The 17th site, not illustrated in the report, was Littrow, for which MSC identified two elliptical landing sites. Table 31 lists all sites discussed at that GLEP meeting and identifies the 17 sites proposed by MSC.

Sources for this section are MSC (1967), a letter from Wilmot Hess to GLEP subgroup members dated 29 November 1967, and the minutes of the GLEP meeting, 8-9 December 1967 (Branch History collection, Flagstaff). The illustrations in Figures 103 and 104 are derived from the original materials, with some cosmetic enhancements, but their quality reflects that of the original materials.

The GLEP subgroup meeting of 8-9 December considered the 17 MSC preliminary sites and 20 others in images which became available slightly later, and began to formulate plans for later landings outside the Apollo zone. All 37 sites are listed in Table 31 in the order listed in the meeting minutes. Of these, 24 were also recommended by USGS as indicated in the table.

Table 31. Later Apollo sites considered on 8-9 December 1967.

Orbiter site number	name	coordinates	Notes (M = in MSC 1967b)	
IIP-4	Cayley Formation (highland plains)	4° 55' N, 15° 35' E	USGS recommended	
IIIP-12	Flamsteed Ring	2° 20' S, 43° 45' W		
IIIS-18	Mösting C	2° 00' S, 8° 00' W	USGS recommended	
IIIS-23	Fra Mauro Formation (Imbrium ejecta)	3° 50' S, 17° 10' W	USGS recommended	
V-1	Petavius	25° 10' S, 60° 40' E		
V-5.1	Messier	2° 10' S, 47° 16' E		
V-8	Apollo site IP-1 (A-1)	1° 00' S, 42° 56' E		
V-14	Littrow Rilles	22° 12' N, 29° 20' E	USGS recommended	(M)
V-15.1	Dawes	17° 12' N, 26° 20' E		(M)
V-18	Dionysius	2° 42' N, 18° 00' E	USGS recommended	(M)
V-21	Highlands south of Alexander	38° 30' N, 13° 30' E		(M)
V-22	Sulpicius Gallus	21° 00' N, 9° 20' E		(M)
V-23.1	Hyginus Rille	8° 03' N, 6° 00' E	USGS recommended	(M)
V-24	Hipparchus	4° 45' S, 4° 05' E	USGS recommended	
V-26	Hadley Rille	26° 52' N, 3° 00' E	USGS recommended	(M)
V-28	Alphonsus	13° 40' S, 4° 10' E	USGS recommended	(M)
V-29	Rima Bode II	12° 50' N, 4° 00' W	USGS recommended	
V-30	Tycho	41° 45' S, 11° 30' W	USGS recommended	
V-31	Rima Plato	49° 30' N, 2° 40' W	USGS recommended	
V-32	Eratosthenes	13° 25' N, 10° 35' W		
V-33	Copernicus CD	6° 25' N, 14° 45' W	USGS recommended	(M)
V-34	Fra Mauro crater	7° 12' S, 16° 45' W	USGS recommended	(M)
V-35	Copernicus secondaries	14° 40' N, 16° 15' W		(M)
V-36	Copernicus H	6° 52' N, 18° 15' W	USGS recommended	
V-37	Copernicus crater	10° 25' N, 20° 18' W	USGS recommended	(M)
V-38	Imbrium flows	32° 40' N, 22° 00' W	USGS recommended	(M)
V-40	Tobias Mayer dome	13° 10' N, 30° 55' W	USGS recommended	(M)
V-41	Vitello	30° 25' S, 37° 25' W	USGS recommended	
V-43.1	Gassendi	16° 52' S, 40° 00' W		
V-45.1	Jura – Gruithuisen domes	35° 55' N, 41° 30' W	USGS recommended	(M)
V-46	Harbinger mountains	27° 15' N, 43° 38' W	USGS recommended	
V-48	Aristarchus	23° 15' N, 47° 25' W		
V-49	Schröter's Valley	25° 09' N, 49° 30' W		
V-50	Aristarchus Plateau	28° 00' N, 52° 45' W	USGS recommended	(M)
V-51	Marius Hills	13° 45' N, 56° 00' W	USGS recommended	(M)
V-12	Censorinus	0° 26' S, 32° 43' E	USGS recommended	
V-19	Abulfeda	14° 50' S, 14° 00' E		

From this list the subgroup selected for the third landing three 1.5 km circular candidate sites at Censorinus, Littrow and Abulfeda, in that order of preference. Mösting C or Fra Mauro would replace Censorinus if it proved unacceptable. They also chose seven 5 km diameter sites, not ranked, for future consideration: Littrow (if not used for the third landing), Hyginus, Hadley, Tycho, Copernicus (crater floor), Schröter's Valley and Marius Hills.

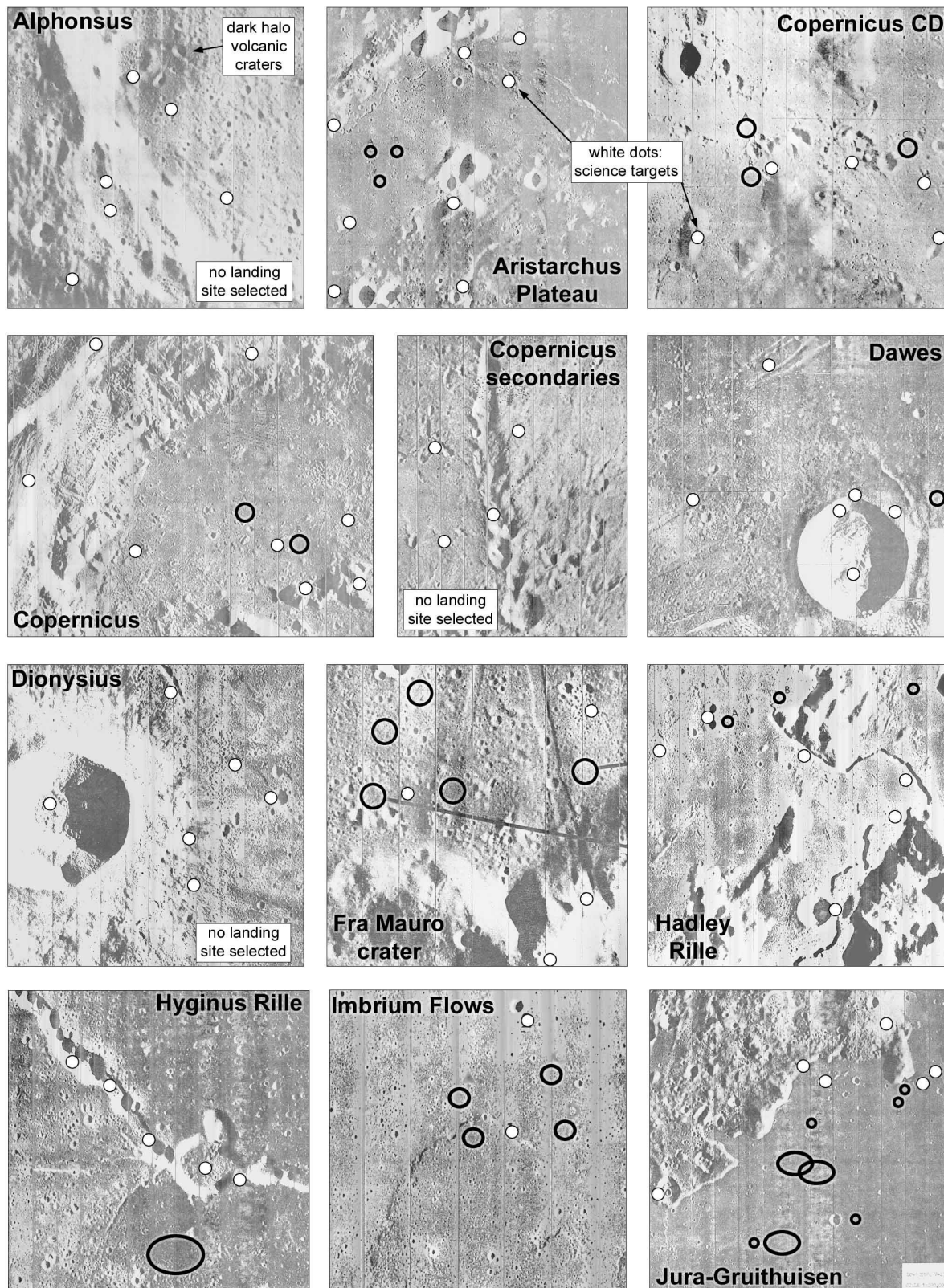


Figure 103. Sites from MSC (1967), listed in Table 31. White dots are science targets. Black circles and ellipses are landing sites. For scale, circular landing sites are 1 km in radius.

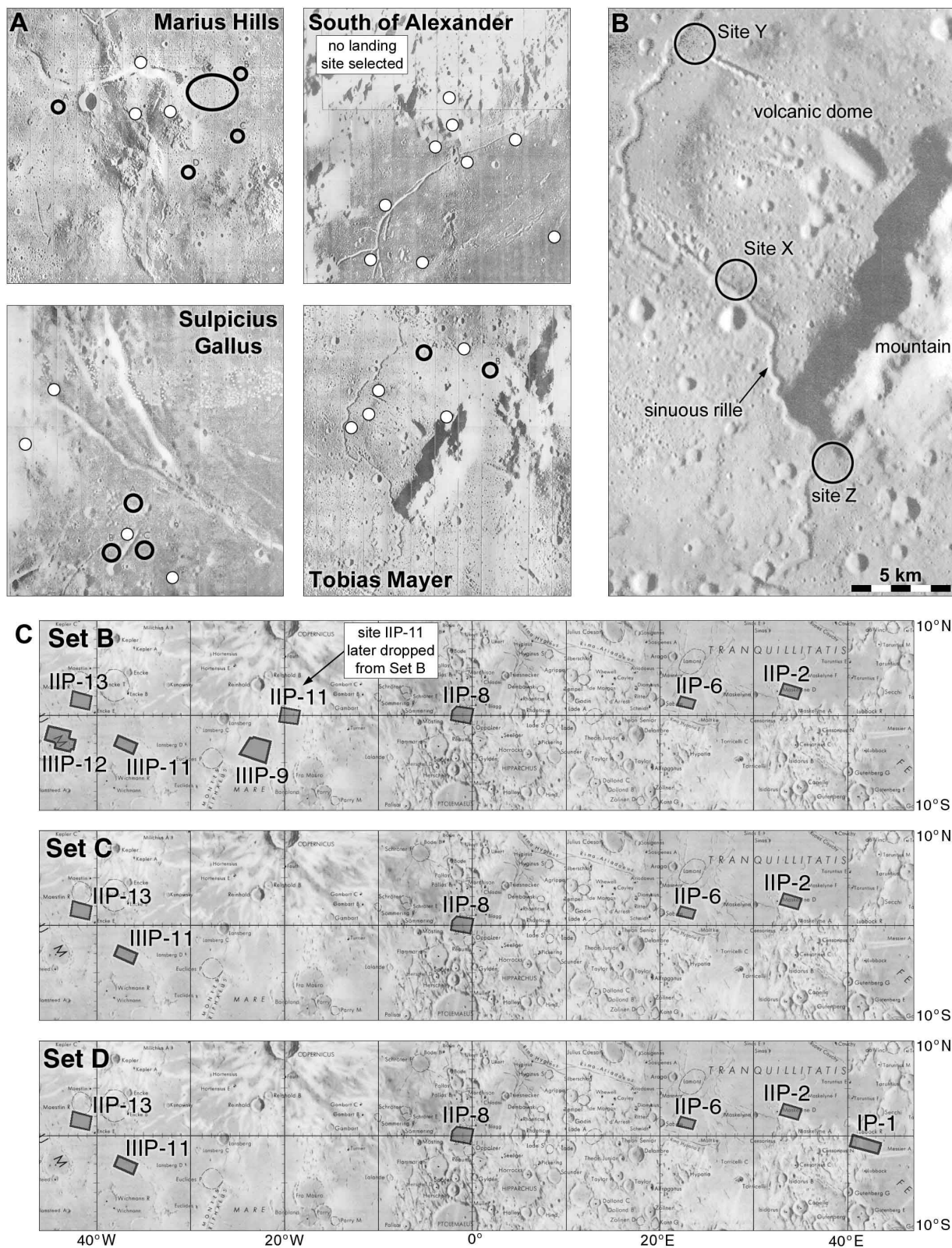


Figure 104. Apollo landing sites. A: four sites from MSC (1967), continued from Figure 103. White dots are science targets, black circles and ellipses are landing sites. B: sites at Tobias Mayer from Hinners *et al.* (1968) on Orbiter 5 frame V-164-M. C: Apollo sites forming sets B, C and D from the ASSB meeting on 15 December 1967.

MSC, 1967. *A preliminary evaluation of landing areas for potential AAP sites*. Mapping Sciences Branch, MSC, Houston, November 1967.



15 December 1967: Apollo Site Selection Board

The Board met at Houston to choose sites for the first two missions and to plan future activities. Five sites (Figure 73) had been chosen at the previous meeting (30 March 1967), and now three more were added from Lunar Orbiter 3 coverage to give the final set of eight Set B sites as defined on 15 December 1966. MSC analysis of LM approach paths initially suggested that all eight sites were acceptable, but site IIP-11 was soon dropped as the hills to its east violated the landing radar constraint. John Eggleston, head of MSC's Lunar and Earth Sciences Division, recommended five of the best remaining sites (Set C) for the first landing mission. To take advantage of the large amount of work already done, the same five sites plus a sixth were chosen for the second mission. This grouping was called Set D at this meeting, but was referred to as Set C, Mission 2 at the next ASSB meeting. The sixth site was IP-1, which was considered uncertain earlier but had now been seen at high resolution in Orbiter 5 images (Figure 84B).

Sets B, C and D are shown in Figure 104C, plotted on the same base as Figures 49, 73 and similar maps. These sites, as the term was used here, were now specific ellipses within the larger Orbiter imaging sites, not the larger imaging sites themselves. A discussion of EVA planning at this meeting is illustrated in Figure 87D.

Eggleston and Wilmot Hess, the head of MSC's Science and Applications Directorate, then indicated the need to start evaluating sites for the third and later landings, particularly sites geologically different from those already chosen. Highland sites in or near the Apollo zone were particularly desirable.

While recognising in principle that the third landing could visit a more challenging site, Board chair Sam Phillips was inclined to be more cautious and suggested looking for science targets within the already certified Set B sites. U.S. Geological Survey staff pointed out that moving the landing point a short distance inside some existing ellipses could bring the astronauts within walking distance of scientifically interesting features such as hills, mare ridges or large craters. This suggestion resulted in a new set of landing targets at the next ASSB meeting.

At this ASSB meeting, seven of the eight Set B sites were portrayed in maps showing the chosen ellipse and hazards such as rocks and rough terrain (Figure 105). Base maps are the contemporary maps of the sites, as follows. **Site IIP-2:** U.S. Army Map Service (AMS) lunar map ORB II-2(100), original scale 1:100 000, 1st edition, December 1967. **Site IIP-6:** AMS lunar map ORB II-6(100), original scale 1:100 000, 1st edition, December 1967. **Site IIP-8:** AMS lunar map ORB II-8(100), original scale 1:100 000, 1st edition, December 1967. **Site IIP-9:** AMS Lunar Map ORB III-9(100), original scale 1:100 000, 1st edition March 1968. **Site IIP-11:** AMS Lunar Uncontrolled Mosaic ORB-3-P 11(100), original scale 1:100 000, 1st edition July 1967. **Site IIP-12:** ACIC Lunar Photomap ORB-I-9.2(100), original scale 1:100 000, 1st edition March 1967. **Site IIP-13:** AMS lunar map ORB II-13(100), original scale 1:100 000, 1st edition, December 1967. The grid spacing on the IIP-11 map is 5', on the other maps it is 6'. Site IIP-11 had already been dropped. Context maps showing these ellipses are found in Figures 59 and 73. The ellipses selected from those maps are identified here using the designation previously given to the entire Lunar Orbiter imaging site, so ellipse IIP-11 is the preferred ellipse from site IIP-11. Some of these final ellipses are slightly different from those shown on the above pages.

The second landing site would be chosen from Set D (Figure 104C), but the choice would depend on which site was used for the first landing. Table 32 shows the landing site options for Apollo landing mission 2, taking into account the choice for mission 1. If mission 1 failed to land, Set C would be used again for mission 2. Otherwise the choices shown here were recommended. The U. S. Geological Survey staff on ASSB urged that if the first landing site was in an eastern mare the second should be in a western mare to take advantage of their different characteristics as suggested by telescopic and Lunar Orbiter images. The western maria seemed to be younger and slightly different in colour properties, suggesting a different composition.

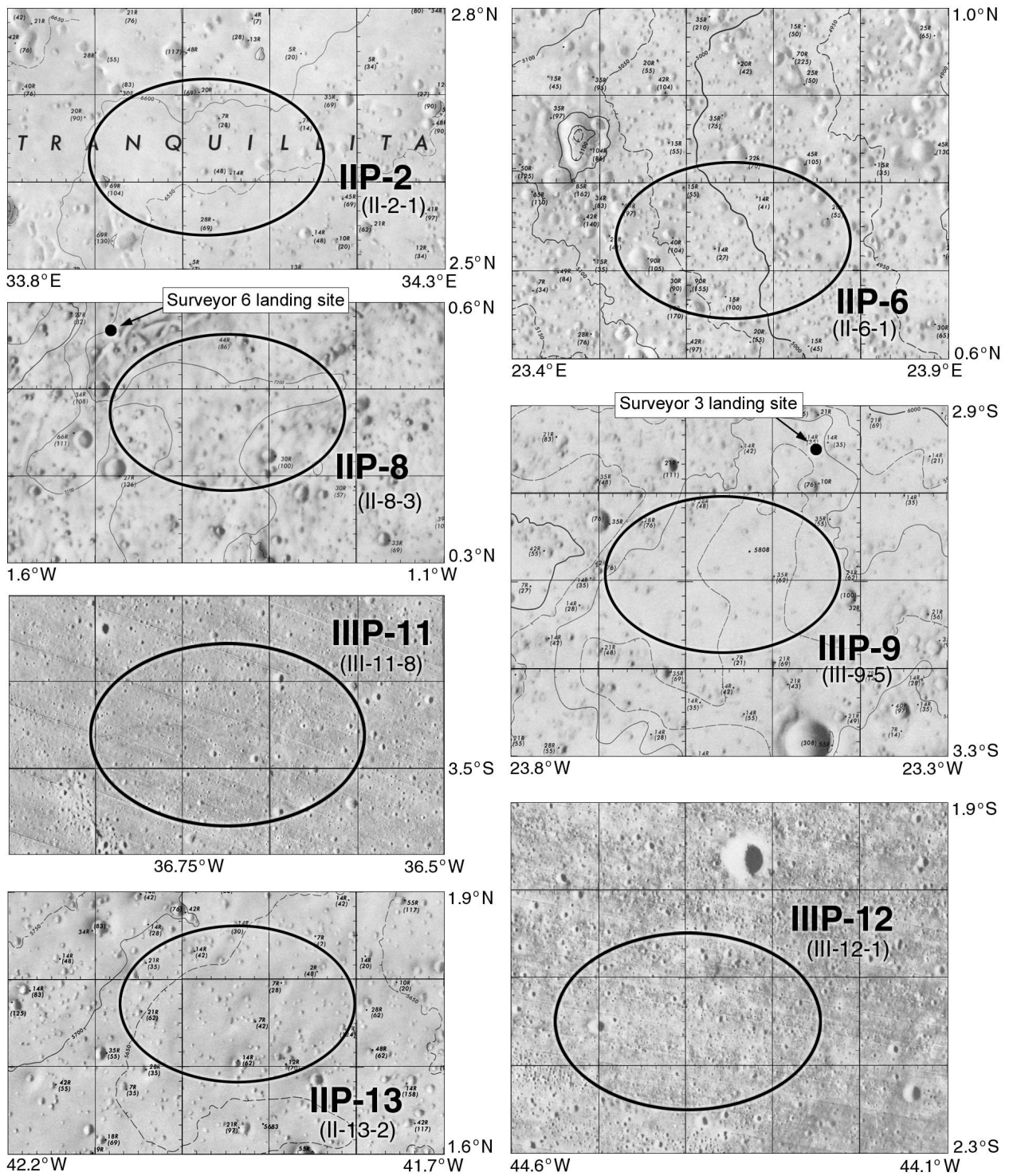


Figure 105. Set B Apollo sites from the 15 December 1967 meeting of the ASSB.

Table 32. Landing site choices for mission II (Set D)			
Mission I landing site	Mission II choices (launch opportunities in a given month)		
	First opportunity	Second opportunity	Third opportunity
II-P-2	I-P-1 or II-P-6	II-P-8	II-P-13 or III-P-11
II-P-6	I-P-1 or II-P-2	II-P-8	II-P-13 or III-P-11
II-P-8	I-P-1	II-P-6	II-P-13 or III-P-11
II-P-13	I-P-1, II-P-2 or II-P-6	II-P-8	III-P-11
III-P-11	I-P-1, II-P-2 or II-P-6	II-P-8	II-P-13

Table 33. Bellcomm Lunar Exploration Program, 1968		
mission	landing site	comments
LLM-1	Any mare	First lunar landing mission (LLM), free return trajectory, must be near equator. Two walking EVAs, 22 hour stay time, no ALSEP.
LLM-2	Mare site	A different near-equatorial site, three walking EVAs in 22 hour stay, ALSEP.
LLM-3	Mare crater	Not free return, more choice of targets. Fresh crater provides samples excavated from depth. Three EVAs, more than 22 hour stay time, ALSEP.
LLM-4	Mare ridge	Samples from a 'wrinkle ridge', three EVAs, over 22 hour stay time, ALSEP.
LLM-5	Boundary area	Mare-highland boundary, first highland samples, 36 hour stay, four EVAs, ALSEP.
LLM-6	Tobias Mayer	First ELM, 3 day stay, six walking EVAs to explore volcanic features.
LLM-7	Site IP-1	Similar to LLM-6, linear rille and highland boundary.
LLM-8	Flamsteed	First use of Lunar Flying Unit (LFU), landing near Surveyor 1 site.
LLM-9	Fra Mauro	Similar to LLM-8, at a site with rilles and domes, possibly volcanic features.
LLM-10/11	Hyginus Rille or Davy craters	Dual landing, pinpoint (100 m) landing capability, 14 day stay with LFU, rover, deep drill equipment and a deployed instrument station with a 10 year lifetime.
LLM-12/13	Marius Hills	Similar to previous landing.

GLEP and Bellcomm were also continuing to devise plans in this period. On 13 and 14 November 1967 GLEP emphasized the importance of continuing scientific exploration with greater capabilities after the first successful landing. Kennedy's original goal made no mention of science and would have been fulfilled with a single landing and no sample collection. GLEP recommended that the human exploration capabilities be extended by continuing unmanned missions. At a meeting on 11 January 1968 (immediately after the successful landing of Surveyor 7) the group proposed flying an additional Surveyor mission, augmented with a seismometer and an alpha-scattering instrument, and suggested it be sent to a high latitude highland site.

On 26 February they proposed flying a Lunar Orbiter 6 (or possibly more, and an Apollo photographic orbiter mission with crew was also considered as an option). This would undertake multispectral compositional mapping, infrared imaging and global metric camera photography with 10 or 20 m resolution in 1971 or 1972. Resolutions of 1 m would be obtained in selected areas. Plans for Apollo missions to Censorinus, Hadley-Apennine and Marius Hills were also considered. The 1.5 mission concept, which involved landing equipment with a separate Saturn 5 launch and a robotic lander prior to the arrival of the crew, might be necessary for the Hadley-Apennine site to overcome payload limitations.

Hinners *et al.* (1968) described a Lunar Exploration Program plan developed at Bellcomm. It was similar in its technical details to NASA's Lunar Exploration Working Group and other plans of late 1966 (Figure 60, 61, Tables 16, 17), beginning with brief missions using the current Apollo hardware. It would progress through more sophisticated landing missions with an Extended Lunar Module (ELM) to orbital remote sensing missions with a crew, and finally dual landings (involving a cargo-carrying LM remotely landed by the first CSM crew) to permit 14

day stays. The 28-day orbital remote sensing mission included a lunar module stripped and outfitted in the manner of the Apollo Telescope Mount (ATM) launched with the Skylab space station on 14 May 1973. It, and a separate subsatellite, would be left in orbit after the crew returned to continue operations for another six months. The Bellcomm plan involved the missions described in Table 33, in which LLM means Lunar Landing Mission.

The Bellcomm Lunar Exploration Program identified several specific landing sites. A landing site with suggested walking and LFU routes and sampling sites was described for a mission to the northern rim of the ‘ghost’ crater Flamsteed P, 20 km north of Surveyor 1 (Figure 69D). At Tobias Mayer (Figure 104) three targets were identified, small circles with a radius of 1 km at locations giving walking access to interesting features.

Hinners, N. W., James, D. B. and Schmidt, F. N., 1968. *A lunar exploration program*. Bellcomm Tech. Memo. 68-1012-1, 5 January 1968.



1968: Barmingrad

As plans for Apollo progressed, a parallel program continued in the Soviet Union (Zak, 2013). Hardware for cosmonaut landings was being built and tested, and site selection work was under way. As it seemed increasingly unlikely that Apollo could be beaten to the Moon, attention began to shift to the post-Apollo era. One program that was considered in detail from the mid-1960s onwards was a ‘Long-term Lunar Base’ (Dolgosrochnyy Lunnoy Bazy, DLB in its Russian acronym), to follow the first landings and lead to a scientific infrastructure on the lunar surface. DLB was also referred to as Zvezda (Star). DLB would have had a crew of nine working in a nine-unit complex powered by nuclear-generated electricity. The design was supervised by Vladimir P. Barmin, Chief Designer of GSKB SpetsMash (State Union Design Bureau of Special Machine Building), and so the DLB project acquired the nickname ‘Barmingrad’. It was postponed indefinitely in 1974 in favour of Earth-orbiting space stations, largely as a result of the failure to develop a successful heavy-lift launch vehicle. Specific sites for DLB were not chosen, but in its later years it was seen as a source of Helium-3 for fusion reactors on Earth, which would have constrained its location.

Haeuplik-Meusburger, S. and Bannova, O., 2023. Reflections on early lunar base design – From sketch to the first moon landing. *Acta Astronautica*, v. 202, pp. 729-741. <https://doi.org/10.1016/j.actaastro.2022.09.021>
Zak, Anatoly, 2013. *Russia in Space: The Past Explained, the Future Explored*. Burlington, Ontario: Apogee Prime.



07 January 1968: Surveyor 7

This, the last mission of the Surveyor Program, was identical to the previous Surveyors in structure but carried more scientific equipment: a camera with polarising filters, an alpha-scattering instrument (ASI), a surface sampler, bar magnets on two footpads, two magnets on the surface scoop, and several mirrors. The latter were used to see beneath the spacecraft, to provide stereoscopic views of the surface sampler area, and to show lunar material deposited on the spacecraft (JPL 1968; JPL 1969; Jaffe and Steinbacher, 1969; Phinney *et al.*, 1969; Shoemaker *et al.*, 1969).

Surveyor 7 was launched from Cape Kennedy on an Atlas/Centaur booster at 06:30 UT and performed a midcourse correction 17 hours later to direct it to the Tycho landing site. Performance was so good that a planned second

correction was not needed. The Centaur upper stage passed 19600 km from the Moon and entered solar orbit. The spacecraft landed safely 66.5 hours after launch, on 10 January at 01:06 UT, at 41.11° S, 11.45° W. 20,993 television pictures were taken during the first lunar day and an additional 45 pictures during the second lunar day. The alpha-scattering instrument failed to deploy successfully, but the surface sampler was able to free it and place it on the surface, later moving it to two new locations. Surveyor 7 also took pictures of the Earth, stars and laser beams transmitted from Earth. Operations continued after local sunset on the first lunar day. These included Earth and star pictures and observations of the solar corona.

Operations ceased 80 hours after sunset, at 14:12 UT on 26 January (Callan, 1968). The spacecraft was reactivated on 12 February and operated until 00:24 UT on 21 February under reduced power. The surface sampler could not be used on the second day, but some new pictures were taken. These included images of areas hidden by the spacecraft's central mast during the first day, now made visible by motion of the spacecraft during the night caused by the collapse of a shock absorber (or possibly by an arm movement at the end of the first day). This triumphant conclusion to the Surveyor program paved the way for the Apollo landings and encouraged planning for future robotic Mars landers.

Surveyor 7 was freed from the constraint of visiting a site in the Apollo zone after the success of four of the six previous Surveyors. The goal was to obtain data at a site topographically and compositionally different from the mare targets of previous missions. Prime candidates were Copernicus, Fra Mauro and Hipparchus as well as Tycho, the eventual choice. During launch preparations the Hipparchus site (4.95° S, 3.88° E; Figure 106B) was entered in the launch vehicle software, allowing the other sites to be reached by designing a suitable mid-course trajectory correction. A plains area east of Fra Mauro at 5° S, 13° W (Figure 106C) was the backup site. This might have offered a dramatic view of the hill Lalande η (eta). After launch the unbraked impact point, where the spacecraft would crash if no correction or braking occurred, was at 5.936° S, 5.392° E (Figure 106B). Callan (1968) gives the unbraked impact location as 6.05° S, 5.39° E, 77 km from the initial target. The midcourse correction targeted Surveyor 7 to 40.87° S, 11.37° W, on the ejecta blanket of Tycho, a young highland crater far south of the previous landings (Figure 106D). Tracking suggested a landing at 41.059° S, 11.451° W. The spacecraft was eventually located in Lunar Orbiter images at 40.92° S, 11.45° W in contemporary coordinates, 40.981° S, 11.513° W in LRO coordinates (Wagner *et al.*, 2017) (Figure 106E).

The lander dropped its retro-rocket before landing, like the previous Surveyors, so its impact site might be visible in LRO images. The search is complicated by the latitude, which precludes the possibility of high sun images. Nevertheless, three small dark spots are visible within a few hundred m of the lander (two to the ENE and one to the WSW (Figure 110C), and another is located on the impact melt pond 1000 m NE of the lander which was the landing target. The distant spot is probably too far away to be correct, but any of the other three might be the retro-rocket impact (Stooke, 2016a; b). All three appear to be small craters in M175355093L, the best LRO image of the site (Figures 110C, 111B, C, D).

Any one of these craters might be the Surveyor 7 retro-rocket impact site. Each is about 3 m across, smaller than the other Surveyor retro-rocket craters. Many of the impact craters near Surveyor 7 are atypical in appearance when compared with craters at other landing sites (Figures 109B, 110C), so a retro-rocket crater may also differ from similar features elsewhere. The existence of more than one dark crater shows that events other than artificial impacts can also form dark ejecta.

Figure 106C shows the Surveyor 7 backup site. Figure 107A shows the final target region, just north of the crater Tycho in a small low-lying area near its rim, which appeared smooth at telescopic resolution. Figures 107C and 107D locate the landing site itself. The target, tracking point and actual location were plotted from the coordinates given above, which were taken from a contemporary map. They were then moved to match surface features in this base map, so the map grid and coordinates appear not to match. Hills A, B and E in Figures 107A and 107B are visible in the surface images (Figure 108). Hill C in Figure 108 is just outside the northern edge of Figure 107A.

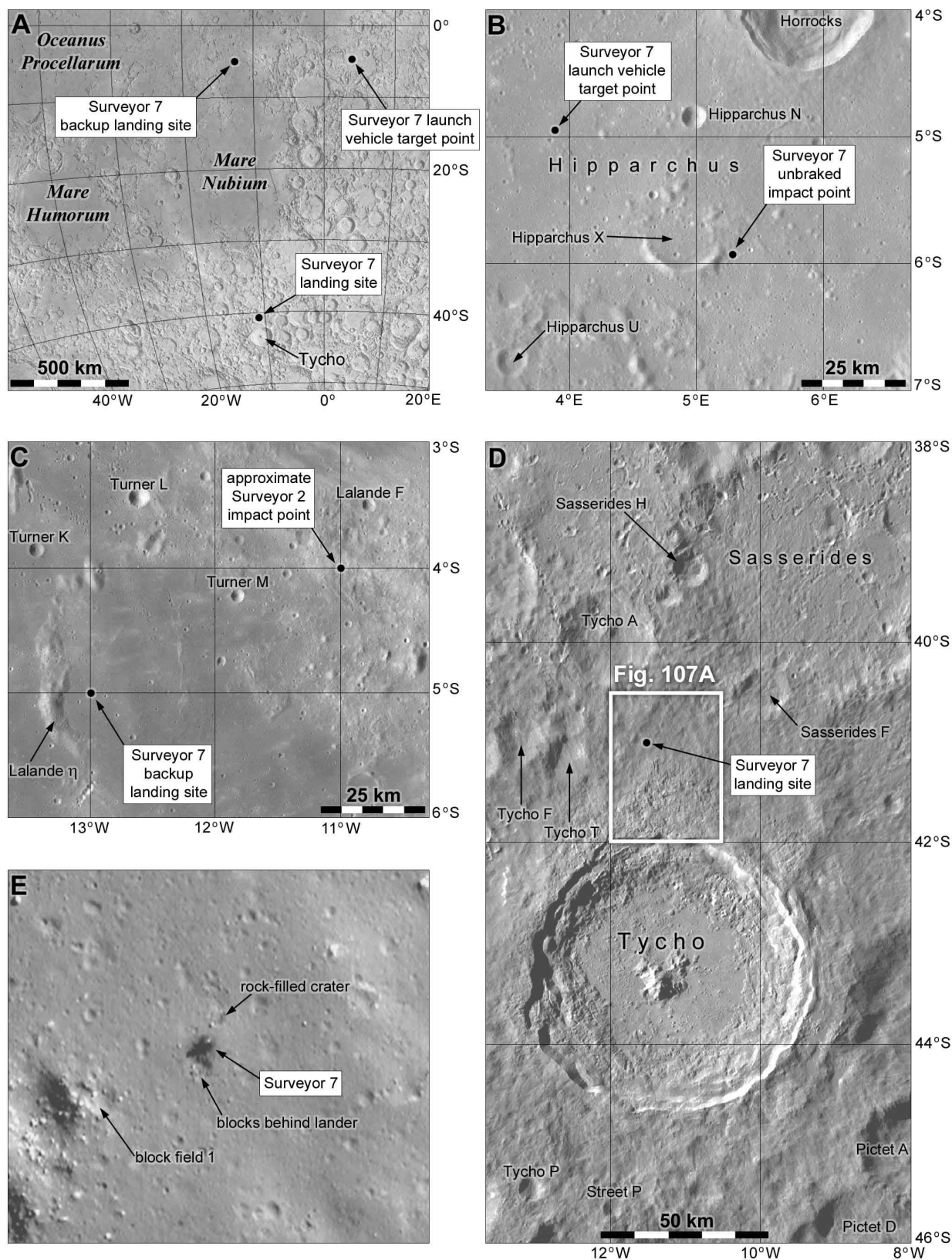


Figure 106. The Surveyor 7 target and landing sites. B, C, D: LROC wide angle mosaics. E: LROC image M175355093L.

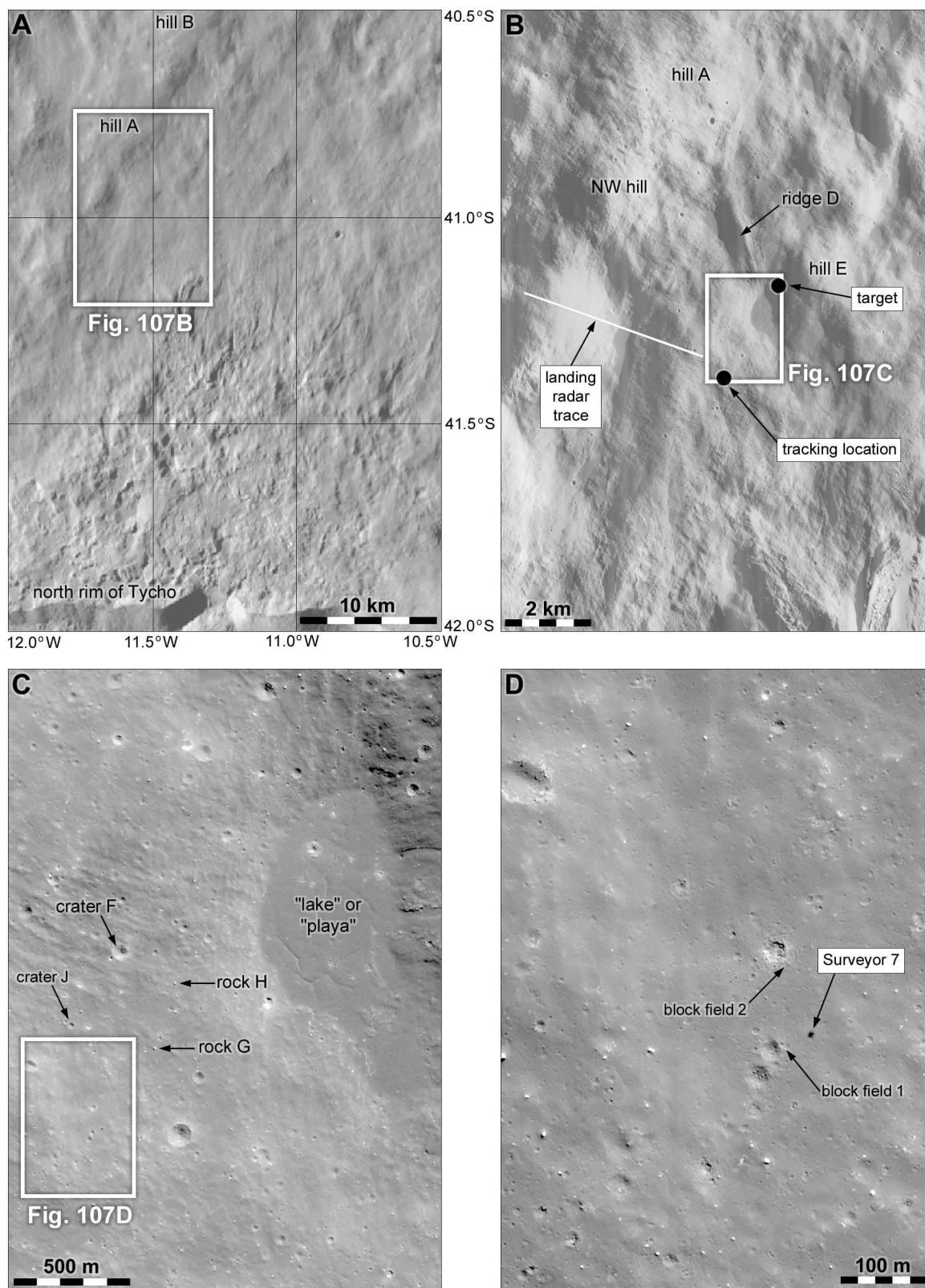


Figure 107: The Surveyor 7 landing site. A: an LROC wide angle mosaic. B: Lunar Orbiter 5 image V-128-H2. The target point, plotted with 1960s coordinates, is probably intended to be on the 'playa' surface. C, D: LROC image M157668488R.

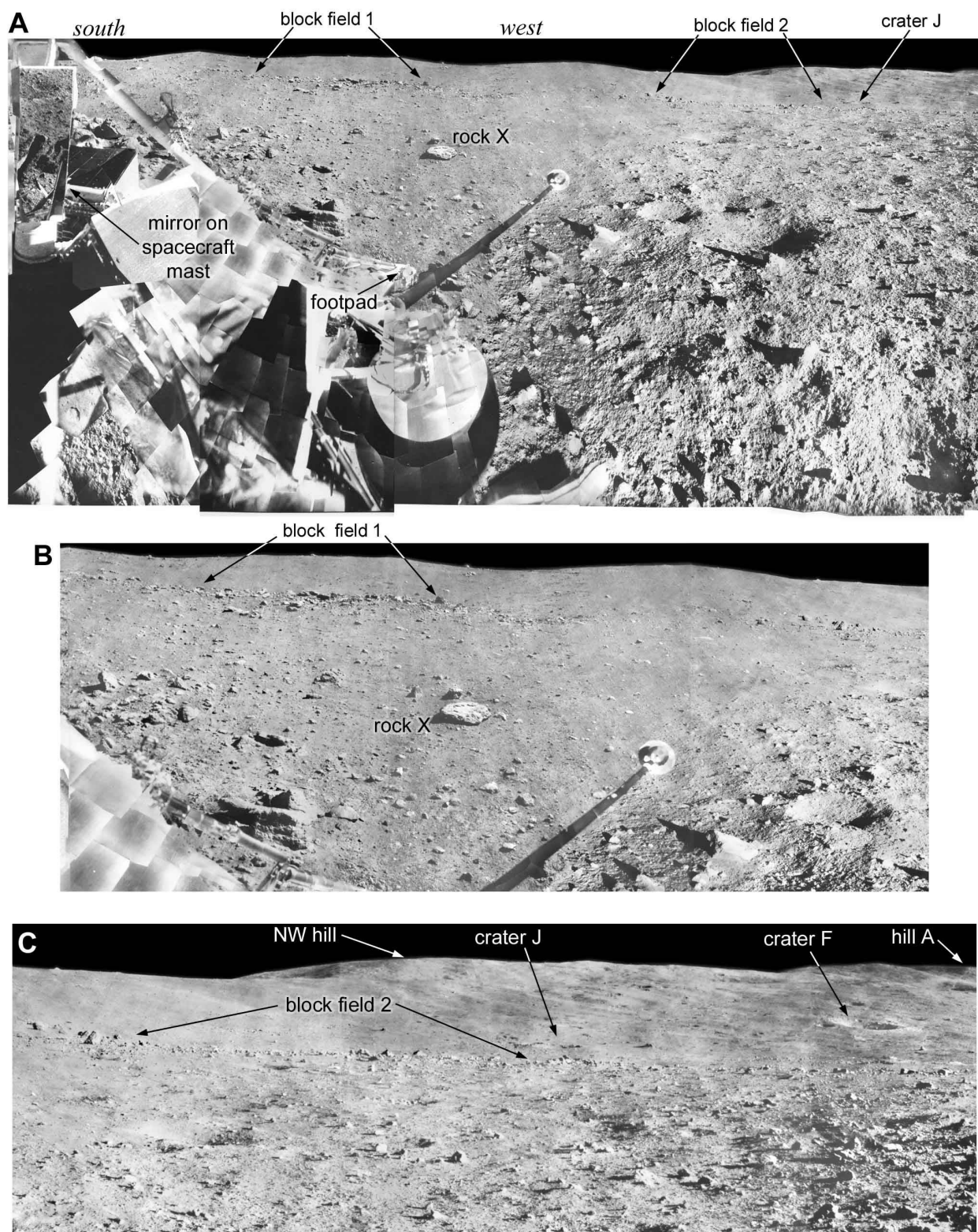


Figure 108 (both pages). Surveyor 7 images. A (both pages): full panorama. B: Block field 1, southwest of Surveyor 7. C: Block field 2, northwest of Surveyor 7. D, E: hills north of the landing site.

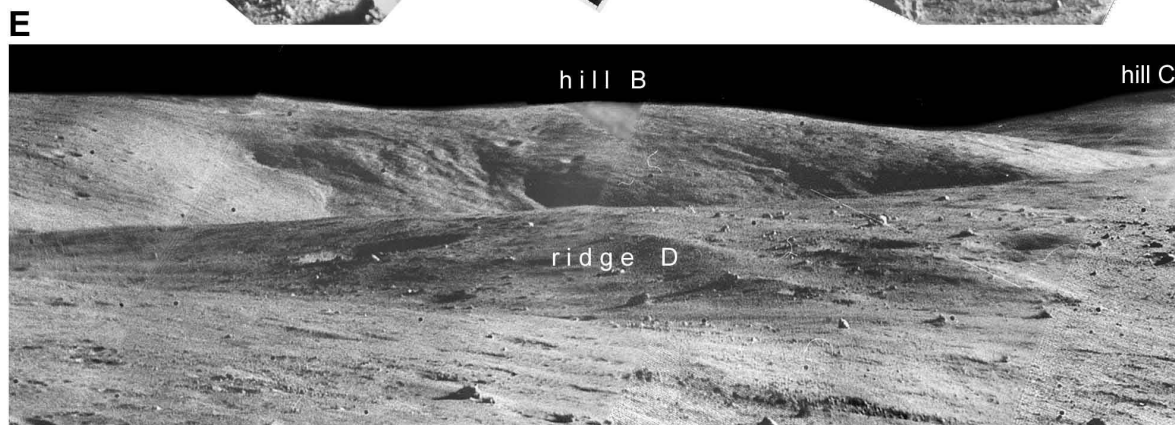
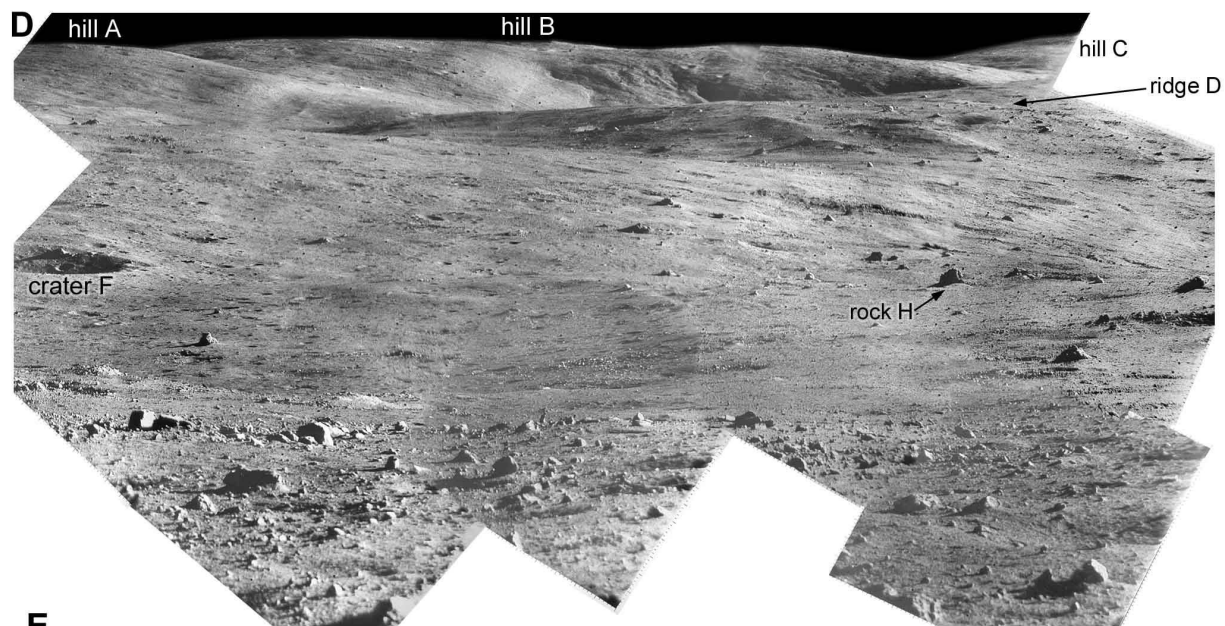
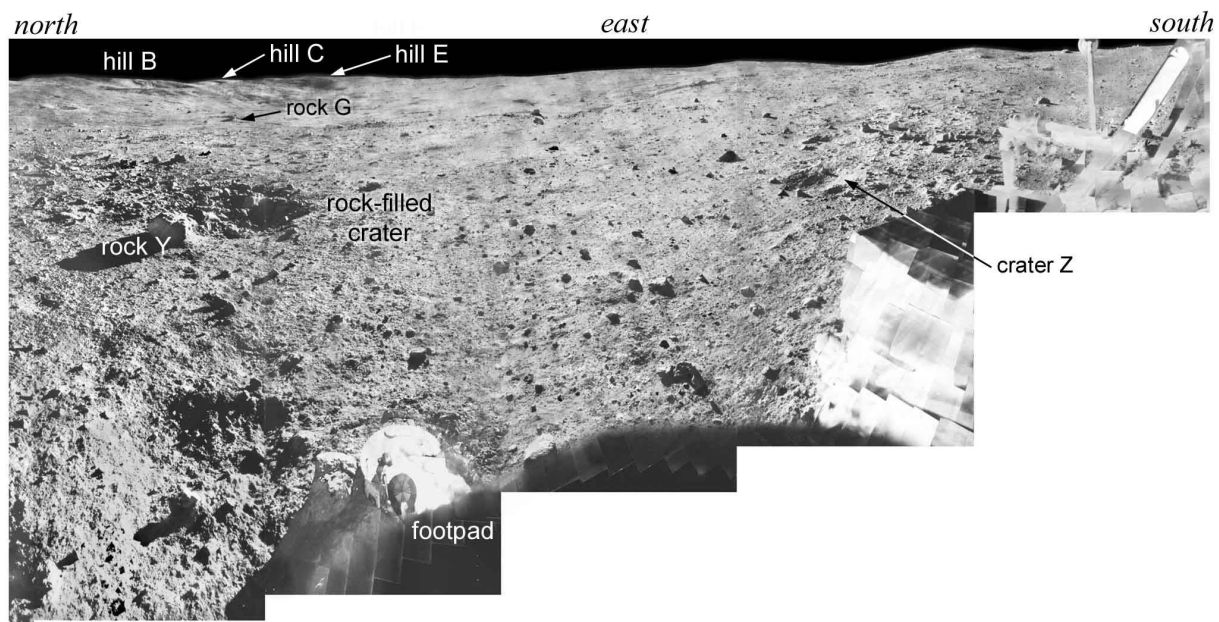


Figure 107C depicts the Surveyor 7 landing site and the area to its north and east, including a distinctive level fractured feature informally referred to as the lake or playa (dry lake bed). This is thought to be a melt pond, formed as rock melted by the Tycho impact and thrown out with other ejecta drained into local depressions in the hours following the impact event. Similar features are common around Tycho and other young lunar craters. The target point is shown, but given coordinate uncertainties it is likely the target was intended to be the 'playa'. The surface of the playa is not visible in Surveyor 7 images as it lies in a local depression blocked from view by intervening terrain features. Ridge D and Hill E are visible in the surface images. The landing radar recorded the presence of the hill whose bright face it crossed just west of the landing site. Tracking suggested a landing just south of this image. The rims of two craters southwest and northwest of the spacecraft are visible as block fields seen in the panoramas (Figures 108B, 108C).

Figure 109 is a detailed plan of the immediate surroundings of Surveyor 7, derived from Figure III-25 of JPL 1968c. Distances from the spacecraft were estimated by focus ranging (observing which features were in focus for different camera settings). North is at the top. The area is 20 m across and slopes gently downwards to the north. Surveyor 7 is shown at the correct scale and orientation. The 3 m wide rock-filled crater about 5 m NNE of the spacecraft is shown in the panorama (Figure 108). A cluster of large rocks immediately south of the spacecraft was partly hidden by the spacecraft structure. Figure 109B reveals that they lie on the floor and rim of a 10 m diameter crater which was just missed by Surveyor 7.

Table 34 gives details of the daily surface operations of the surface sampler, the remotely controlled arm (Scott and Roberson, 1969). The days in Table 24 are dates in January 1968. On the second lunar day there was insufficient power to operate the sampler. The surface activities are mapped in Figure 110. Bearing tests (b1, b2 and so on, in Table 34 and Figure 110A) were performed by pressing the sampler down on the surface, and impact tests were done by dropping the arm to strike the surface. Rock A was weighed and imaged in stereo to estimate its volume and derive its density. Rock E was broken by dropping the sampler on it, and the broken surface was photographed. Seven trenches were dug to investigate the regolith's mechanical properties. Trenches 1, 2 and 6 were dug with multiple sampler passes, the others just with one. A buried rock in trench 1 prevented deep digging at that location, and at the end of the first lunar day the arm was placed just beyond the rock and retracted in an experiment to move either the rock or the spacecraft itself. The photomosaic in Figure 110B was made on 21 January with the sampler in trench 6. A small mirror mounted on the mast (Figure 108A, top left) provided a different view of part of the trench area to enable topographic modelling of the trenches.

Table 34. Surveyor 7 sampler operations (Scott and Roberson, 1969)

day	actions
11 January	Perform bearing tests b1 and b2. Attempt to deploy ASI with sampler.
12	Bearing tests b3, b4 and b5. Pick up and weigh rock A, drop it at A'. Deploy ASI at ASI-1.
13	Reach for rock B, pick up rock C and drop it at C'. Dig trench 1. Leave sampler shading the ASI at the end of the work day.
14	Reach for rock D, move it but fail to pick it up, leave sampler shading ASI.
15-18	Move sampler to shade ASI as the Sun moves (too hot to operate sampler around local noon).
19	Pick up rock A (at A'), weigh it and drop it at A''. Perform bearing test (not numbered) on rock A, then b6 near C'. Dig trench 2 from the b6 location, leave sampler in trench at the end of the day.
20	Finish digging trench 2. Bearing tests b7, b8 and b9. Dig trench 3. Bearing tests b10 and b11. Dig trench 4. Magnet scrape test. Leave sampler shading ASI at the end of the day.
21	ASI lifted to calibrate rock weights, then placed over rock at ASI-2. Bearing test b12. Dig trench 5. Bearing test b13. Dig trench 6, and leave sampler in trench at the end of the day.
22	Finish trench 6. Bearing test b14. Dig trench 7. Move ASI to ASI-3 on the trench 7 tailings. Impact tests i1 and i2, bearing tests b15 and b16. Break rock E by impact of sampler, and leave sampler in trench 1.
23	Sunset, retract sampler against the buried rock in trench 1 to move either the rock or the spacecraft.

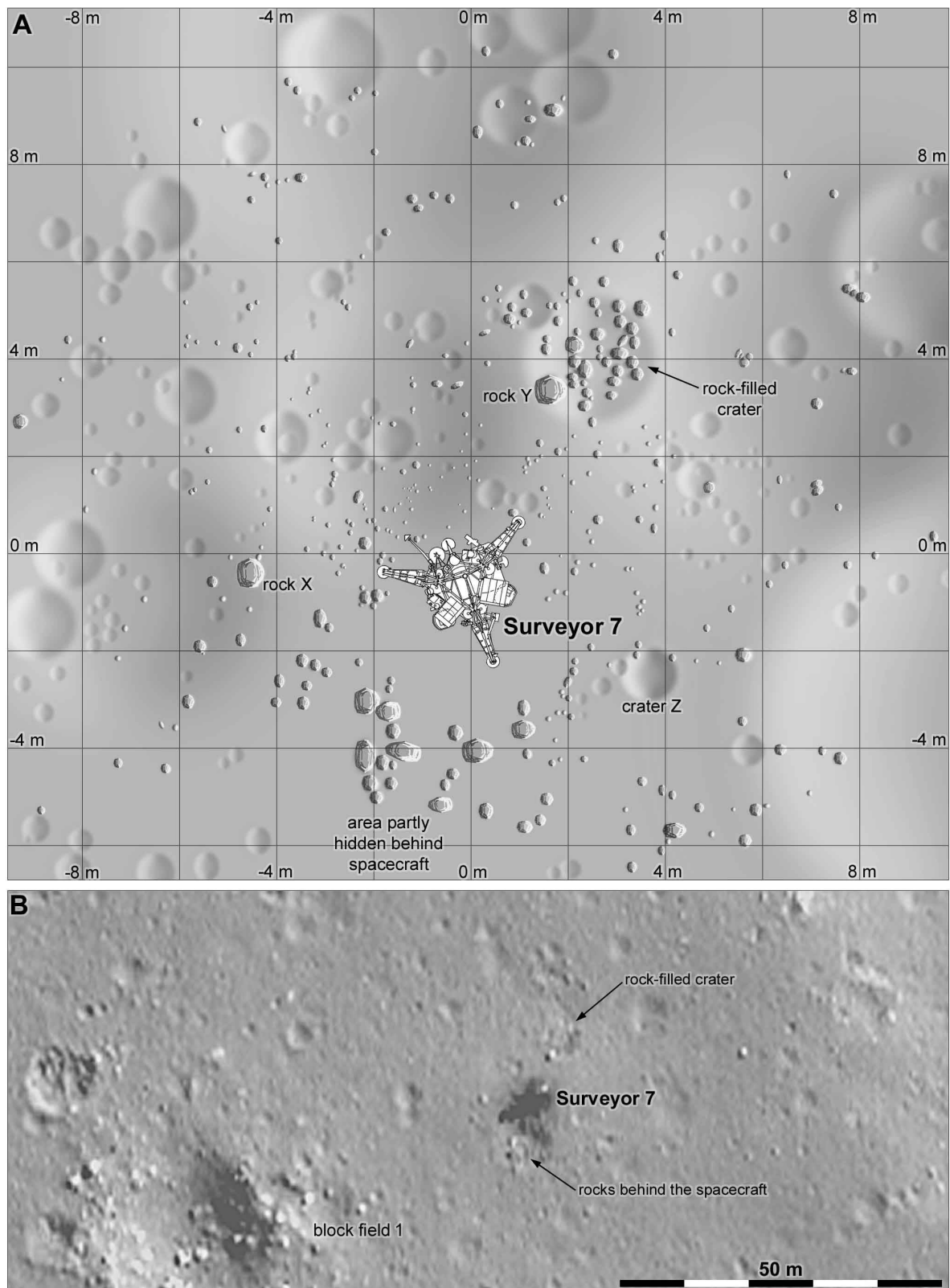


Figure 109. Surveyor 7 landing site details. A: map by P. Stooke derived from a drawing in JPL (1968). B: detail of LROC image M175355093L.

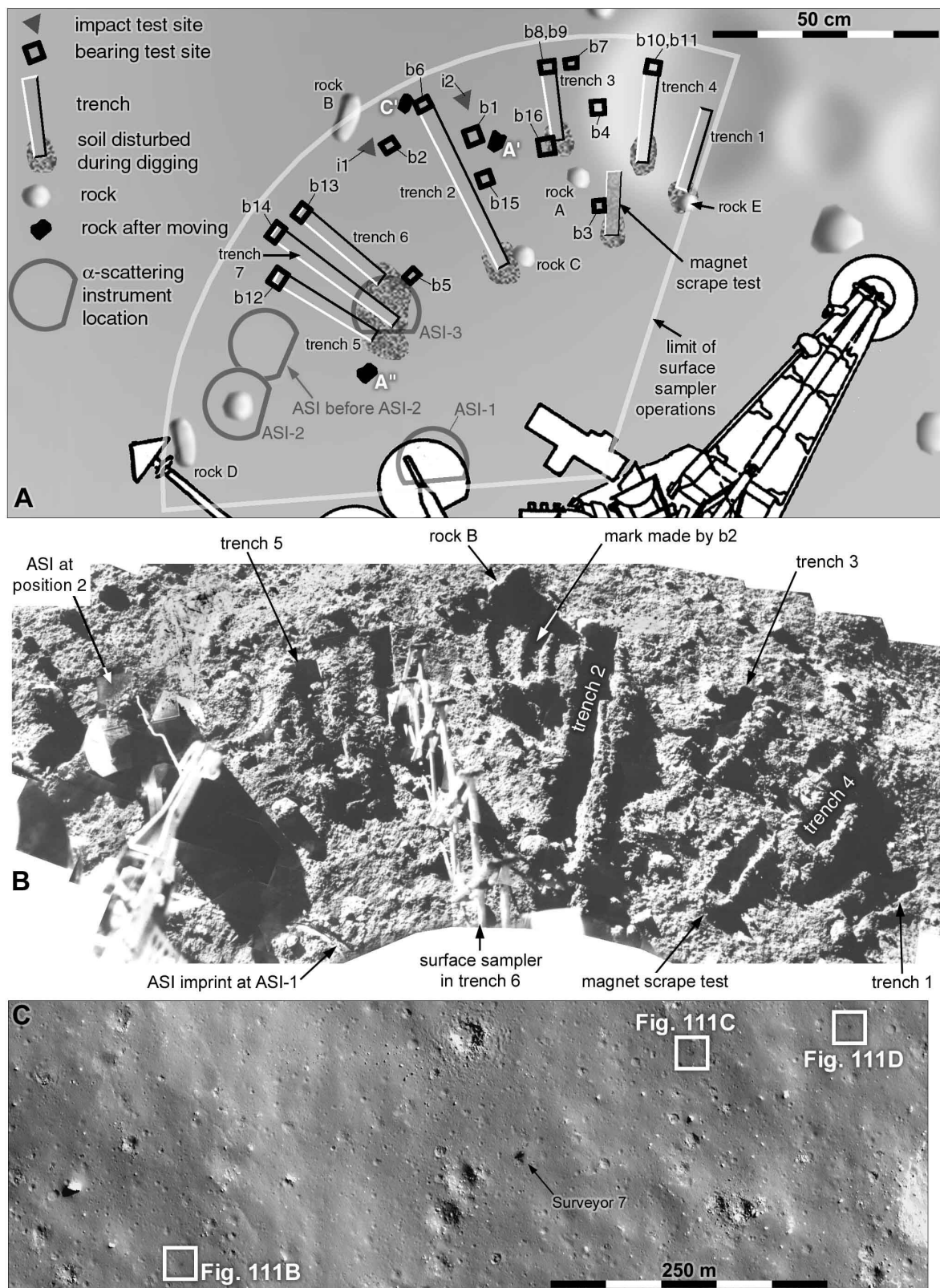


Figure 110. Surveyor 7 site. A: plan of sampler arm activities. B: mosaic of the sample area. C: part of LROC image M175355093L showing three candidate retro-rocket impact craters.

The alpha-scattering instrument provided composition data (Patterson *et al.*, 1969). Its locations are shown in Figure 110A. After being freed by the sampler it fell to position ASI-1 and examined undisturbed regolith. Later the sampler moved it to ASI-2 to examine a rock, placing it initially beside the rock and then moving it over the rock. Finally, trench 7 was dug to help create a large patch of disturbed material (tailings) and the instrument was moved to ASI-3 to examine that material. All results were similar and differed from the Surveyor 5 and 6 samples in that they contained less iron. The magnet scrape test searched for regolith particles adhering to a magnet on the sampler scoop.

Images taken about one hour after sunset showed a bright fringe along the western horizon (Rennilson and Criswell, 1974). They were interpreted as sunlight passing through a rarified dust cloud caused by electrostatic charging of dust particles. Micrometeorite impacts would not be able to generate enough elevated dust. Similar effects were also seen by Surveyor 6 and possibly Surveyor 5. The phenomenon would not be observed again until Firefly Aerospace's Blue Ghost Mission 1 in 2025.

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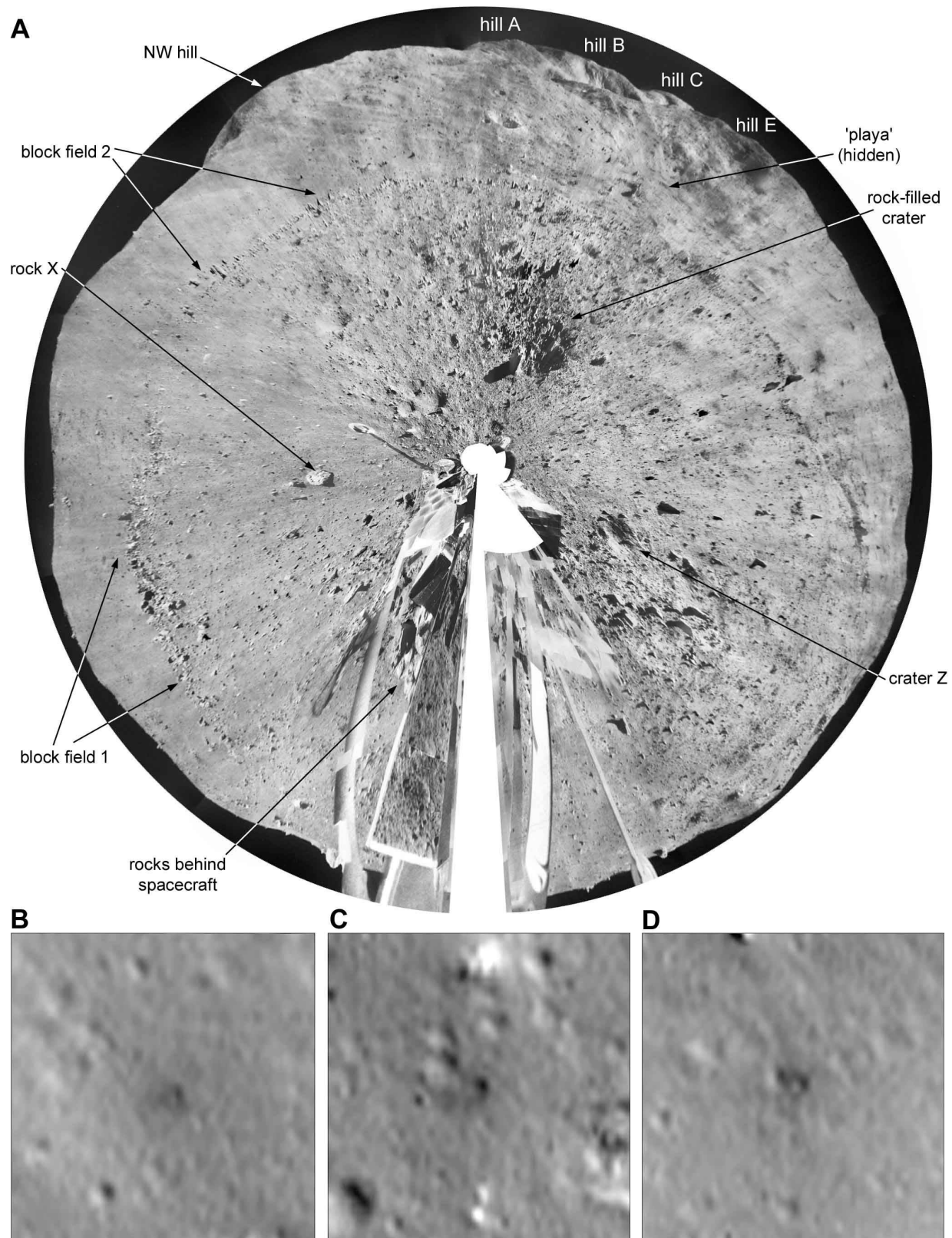


Figure 111. Surveyor 7 landing site. A: reprojected Surveyor 7 panorama. B, C, D: details of Figure 110C showing candidate retro-rocket craters. Each image is 30 m wide.

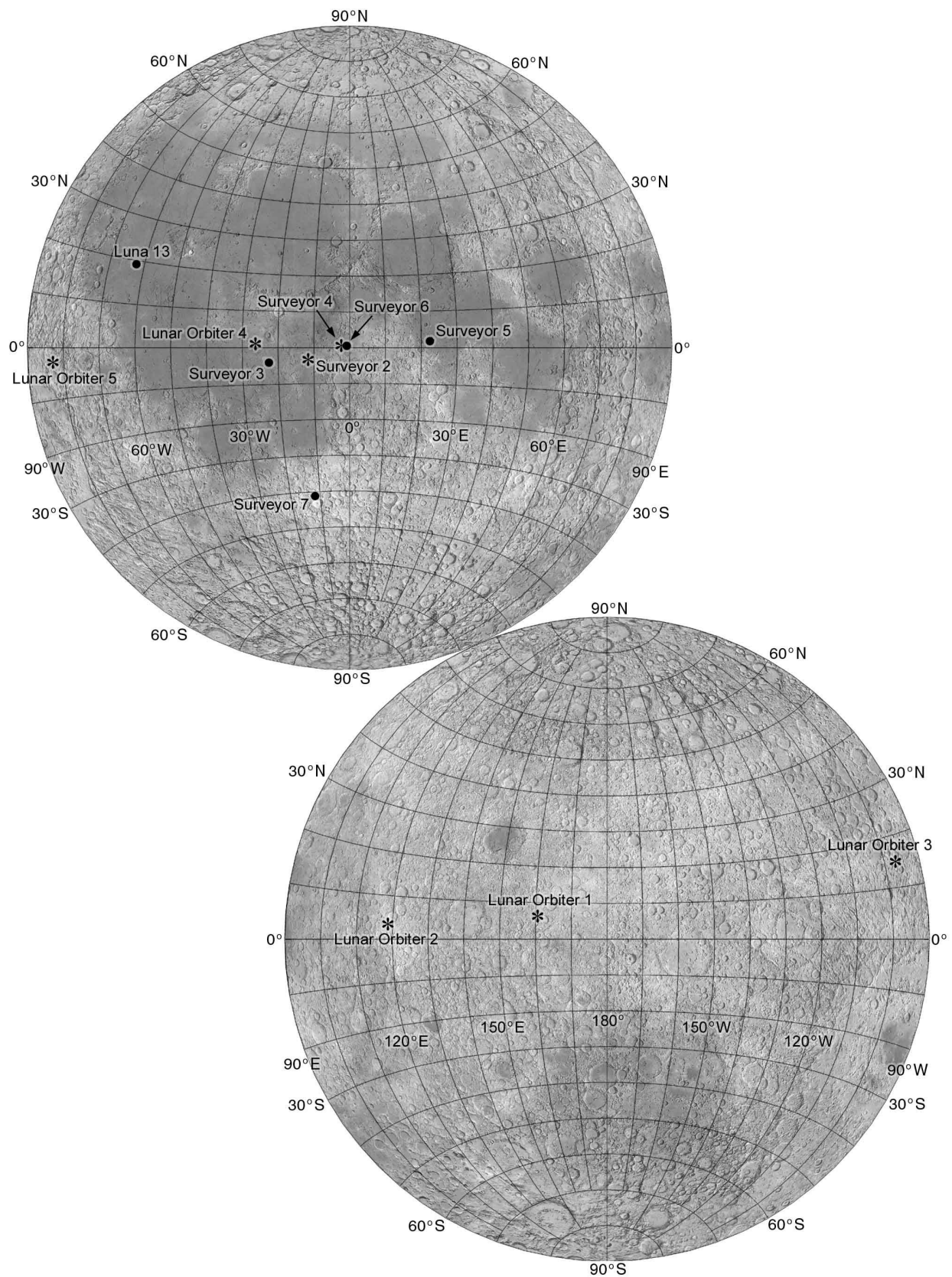


Figure A1. Lunar landings and impacts covered in this volume.

Table A1. Spacecraft locations on the Moon, from this volume.			
Spacecraft	Date of contact	Location	Event
Surveyor 2	22 September 1966	4° S, 11° W	Impact
Lunar Orbiter 1	29 October 1966	7° N, 161° E	Impact
Luna 11	unknown	unknown	Impact
Luna 12	unknown	unknown	Impact
Luna 13	24 December 1966	18.9° N, 62.1° W	Landing
Surveyor 3	20 April 1967	3.015° S, 23.418° W	Landing
Surveyor 4	17 July 1967	0.43° N, 1.62° W	Impact
Surveyor 5	11 September 1967	1.461° N, 23.195° E	Landing
Lunar Orbiter 3	9 October 1967	14.3° N, 92.7° W	Impact
Lunar Orbiter 2	11 October 1967	3.0° N, 119.1° E	Impact
Lunar Orbiter 4	No later than 31 October 1967	c. 0° N, 25° W	Impact
Surveyor 6	10 November 1967	0.473° N, 1.427° W	Landing
Surveyor 7	10 January 1968	40.980° S, 11.509° W	Landing
Lunar Orbiter 5	31 January 1968	2.79° S, 83.04° W	Impact